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# ENGINEERING FIELD MANUAL
for
CONSERVATION PRACTICES

U.S. Department of Agriculture
Soil Conservation Service
1979

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ENGINEERING FIELD MANUAL

for Conservation Practices

PREFACE

The objective of this manual is to provide guidance in the use of basic engineering principles, techniques, and procedures for the planning, design, installation and maintenance of soil and water conservation practices. The material presented is limited to the types of conservation practices which are used most often. Engineering procedures and data for more complex practices are included in the various sections of the SCS National Engineering Handbook.

The manual is intended primarily for use at the work unit level. The basic principles of planning, design, construction and maintenance of engineering measures are essentially the same regardless of the job location. But, to assure the applicability of the manual nationally, it was necessary to treat certain portions of the text in a more general manner than would have been the case had it been prepared for a specific region or area. It is expected that State or regional additions may need to be made to certain sections of the text to conform to local or regional standard practices or to provide more detail.

Most chapters contain a limited number of tables, charts, curves, and forms used in solving planning and design problems. The training of personnel in the use of ths manual may be facilitated if the States insert their approved design aids in the applicable chapters. Design aids which are added should give results consistent with similar ones in the manual.

Except in the chapter on Structures, design aids are labeled as Exhibits and placed at the end of the appropriate chapter. Once the user has become familiar with the techniques and procedures in the manual he may wish to remove the exhibits and bind them in a reference book for field use without destroying the continuity of the text.

The manual is not intended to supersede national or state engineering standards and specifications of the Soil Conservation Service as they pertain to various conservation practices.

Development of this manual was guided by the following committee, assigned by C. J. Francis, Director, Engineering Division, SCS, Washington, D. C.

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J. W. Haas,	State Conservation Engineer, Illinois. Presently Assistant State Conservationist for Watersheds, Pennsylvania.

The specialists who were responsible for compiling the various chapters are credited on the first page of the table of contents.

SECOND PRINTING

The supply of the 1969 Edition is exhausted. All changes made since that time have been incorporated in this printing. Rapid advances in technology and materials make it difficult to keep this handbook up to date. Further revisions, corrections, or additions will be made in the handbooks used by SCS employees as new information becomes available.

Soil Conservation Service

Washington, D.C.
April 1975

THIRD PRINTING

The supply of the 1975 Edition is exhausted. All changes made since that time have been incorporated in this printing.

Soil Conservation Service

Washington, D. C.
June 1979

ENGINEERING FIELD MANUAL

CHAPTER 1. ENGINEERING SURVEYS

Compiled by: Elmer W. Gain, Drainage Engineer, SCS, Upper Darby, Pa.

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ENGINEERING FIELD MANUAL

CHAPTER 1. ENGINEERING SURVEYS

1. GENERAL

DEFINITION

Surveying is the science by which lines, distances, angles, and elevations are established and measured on the earth's surface. From these measurements are determined locations, directions, areas, and volumes. Surveying information obtained and recorded in the field can be represented graphically by diagrams, maps, profiles and cross sections.

PRECISION AND ACCURACY

The required precision and accuracy of a survey will vary with its purpose. Whether the survey is rough or precise, enough checks must be applied to the fieldwork and in the preparation of plans so that unjustified errors are eliminated from the final results.

Precision is the degree of perfection applied in instruments, methods, and observations. Accuracy is the degree of perfection obtained. An objective of surveying is to obtain the required data with the desired accuracy at the lowest cost. Accuracy has been defined for Federal Government surveys and mapping since 1925 by classes of 1st, 2nd, 3rd, and 4th order. Third and 4th order accuracy generally apply in soil and water conservation engineering work as "ordinary" or "rough" surveys.

Ordinary survey accuracy should be attained in establishing bench marks, level circuits involving six or more instrument setups, and surveys for drainage, irrigation, large channels, and other major structural practices. Rough survey accuracy is adequate for level circuits of less than six instrument setups, preliminary and reconnaissance surveys, and surveys for such conservation practices as diversions, waterways and small ponds. (See Table 1-1.)

Surveying skill is obtained only with practice. A surveyor should review and apply surveying procedures until the operations are almost automatic. He should practice working accurately in order to perform accurate surveys when they are required. He should check and recheck his work until assured of its correctness.

ERRORS IN SURVEYING

Each survey presents specific problems. When the principles are mastered, the skilled surveyor has no difficulty in applying the proper method. However, he must understand the limits of the instruments used,

Table 1-1 Specifications for horizontal and vertical control

Type of Survey	Ordinary Surveys	Rough Surveys
Triangulation:		
Maximum error of angular closure	1.0 Minutes $\sqrt{N}$	1.5 Minutes $\sqrt{N}$
Maximum error of horizontal closure		
By chaining	1.0 ft./5000 ft.	1.0 ft./1000 ft.
By stadia	1.0 ft./1000 ft.	3.0 ft./1000 ft.
Traverse:		
Maximum error of angular closure	1.0 Minutes $\sqrt{N}$	1.5 Minutes $\sqrt{N}$
Maximum error of horizontal closure		
By chaining	1.0 ft./5000 ft.	1.0 ft./1000 ft.
By stadia	1.0 ft./1000 ft.	3.0 ft./1000 ft.
Leveling:		
Maximum error of vertical closure		
By level and rod	.10 ft. $\sqrt{M}$	.40 ft. $\sqrt{M}$
By transit and stadia	.30 ft. $\sqrt{M}$	1.0 ft. $\sqrt{M}$
Topographic:	The elevation of 90 percent of all readily identifiable points shall be in error not more than one-half contour interval. No point shall be in error more than a full contour interval.	

N is the number of angles turned.
M is the miles of levels run.

the ever present possibilities of errors affecting the surveying process, and the mistakes that can occur through carelessness.

No surveying measurements are exact. Therefore, errors are continuously dealt with. Although errors result from sources that cannot be controlled, they can be kept within proper limits by due precautions. Errors are either accidental or systematic.

Accidental Errors

Accidental errors are due to limitations or imperfections in the instrument used, either from faults in manufacturing or improper adjustment of parts. They are caused also in the skill applied in determining values with instruments. Accidental errors occur according to the laws of chance. They tend to cancel with repeated measurements. The accidental error in the final result varies with the square root of the number of individual measurements.

Systematic Errors

Systematic errors are those of uniform field conditions which remain constant in sign and magnitude. Measurement of a line with tape of incorrect length is an example. There are also those of changing field conditions which remain constant in sign but in which magnitude varies in proportion to the change. Measurements with a steel tape at low winter temperature and again at high summer temperature is an example.

Mistakes

Mistakes are the result of inattention or carelessness and can be eliminated by care and checking. Misreading a figure or incorrectly recording a direction is an example.

IMPORTANCE OF PLANNING SURVEY WORK

Many man-hours are lost, needed data are omitted, and much useless data are collected because surveys are not carried out in accordance with a carefully prepared plan. The survey plan should contain the following: 1) List of the data needed; 2) best method of obtaining the data; 3) degree of accuracy acceptable; 4) list of the people needed to perform the work; 5) list of needed equipment; and 6) complete time schedule for performing the survey work.

2. FUNDAMENTALS OF SURVEYING

The survey methods used to make measurements and determine direction and position are based on the following techniques.

MEASUREMENT OF DIMENSIONS

Four dimensions are measured. These are horizontal lengths, vertical lengths, horizontal angles, and vertical angles.

Horizontal Length

A horizontal length is the straight line distance measured in a horizontal plane. In most cases a distance measured on a slope is changed to its horizontal equivalent. Measurements are made by direct and indirect methods. Direct measurements are made by wheels, human pacing, and tapes of cloth, metallic cloth and steel. Steel tapes are most commonly used. Indirect measurements are made by use of stadia equipped instruments and graduated rods or by electronic devices. The type of measurement and equipment used depends upon required accuracy, access to the line, and the time and cost involved.

Vertical Length

A vertical length is a measurement of a difference in height or elevation. This can be done by trigonometry, barometric pressures, and differential leveling. Direct measurements can be made by an altimeter which indicates barometric pressure or, for short vertical distances, by plumb line and tape. In most cases remoteness of points and accuracy require indirect measurements with instruments such as the level and graduated rod.

Horizontal Angle

A horizontal angle is the difference in direction between: 1) Two intersecting lines in a horizontal plane, 2) two intersecting vertical planes, or 3) two intersecting lines of sight to points in different vertical planes. It is measured in the horizontal plane in degrees of arc. Horizontal angles usually are measured in a clockwise direction but may be measured counterclockwise.

Angles are usually measured by transit. An angle may be an interior angle if on the inside of an enclosing figure or an exterior angle if on the outside of an enclosing figure. A deflection angle is that angle which any line extended makes with the succeeding or forward line. The direction of the deflection is identified as "right" or "left". An angle-to-the-right is the clockwise angle at the vertex between the back line and forward line.

Vertical Angle

A vertical angle is the difference in direction between a horizontal plane and an intersecting line, plane, or a line of sight to a point. It is measured in the vertical plane in degrees of arc. Measurements are referenced "up" or "down" from the horizontal as "plus angles" or "minus angles".

DETERMINING HORIZONTAL POSITION

The horizontal position of points is determined by traverses, triangulation, or grids, referenced to a known direction and position.

Traverse

A traverse consists of a number of points, called traverse stations, connected in series between horizontal angles by horizontal lengths, which are called courses. Traverses may be open or closed. Open traverses cannot be checked completely without closure. Closed traverses are either loop traverses or connecting traverses. Loop traverses close on themselves. Connecting traverses start and end in known directions and positions.

Triangulation

Triangulation consists of a series of connecting triangles in which a side of one and the angles of all are measured and the remaining sides are computed by trigonometry.

Grid

A grid consists of a series of measured parallel and perpendicular reference lines laid out an equal distance apart to form adjoining tiers of equal squares.

Azimuth and Bearing

The direction of courses or sides of angles is expressed as an azimuth or bearing. An azimuth is a clockwise horizontal angle from a reference direction, usually north. Azimuths cannot exceed 360°. A bearing is the angle defined by both the direction of the earth's geographic poles and the direction toward or against the earth's rotation. Thus, a bearing is either north or south (whichever is nearest) and east or west, i.e. N 48°27'E; S 15°10'E; S 32°30'W; N 20°15'W; etc. Bearings may be measured along the earth's magnetic lines of force by the compass. These magnetic bearings will vary from the geographic or true bearings determined by astronomic observation. Declinations from true bearings vary daily, monthly, yearly, and from place to place but the variances are not in sufficient amounts to affect soil and water conservation engineering surveys. Bearings cannot exceed 90° in value.

Latitude and Departure

The position of a point, line, traverse, triangulation, or grid can be defined by coordinates which are northerly or southerly (latitudes), measured from an arbitrarily chosen east-west or "x" axis; and easterly or westerly (departures) measured from an arbitrarily chosen north-south or "y" axis. North and east directions are taken as positive values and south and west as negative. Given the measurement and direction for one course or side, direction of all other courses or sides can be computed from measured angles or triangulation, traverse, or grid. Some States require that State coordinate systems be used to define survey positions.

DETERMINING VERTICAL POSITION

Level Observations

The vertical position of points is determined from a series of level readings. Since all lines of sight are horizontal, a reference surface of connecting short lines is defined which conforms nearly to a curved surface everywhere perpendicular to gravity.

Datum, Elevation and Bench Mark

Level surveys are referenced to datum. Mean sea level usually is used as standard datum, however, an assumed datum may be used for minor surveys. Vertical distances above a datum are called elevations. A bench mark is a marked point of known elevation.

3. SURVEYING EQUIPMENT

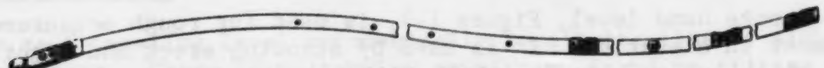
The principal surveying instruments and accessories and their primary use are as follows:

TAPES

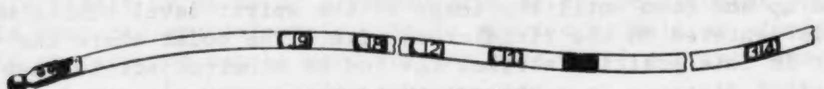
Steel tapes are made of flat steel bands marked in various ways, Figure 1-1. The markings may be etched, stamped on clamps or soldered sleeves, or stamped on bosses. Steel tapes may be obtained in lengths up to 500 feet, although the most commonly used is 100 feet long. Tapes are usually marked at 1-foot intervals, except the first and last foot, which are generally graduated in tenths.

Some tapes may have an extra foot at one or both ends marked in tenths and hundredths. Tapes marked in feet, inches, and eighths of an inch usually are furnished in a leather case and are lightweight steel ribbons as compared with the heavy-duty field engineer's tape. Because of the wide variety in manner of marking tapes, the surveyor should inspect them carefully to determine how they are marked. Tapes using clamped or soldered sleeves for foot markings are commonly used without reels because of their bulkiness when rolled on a reel. Tapes without reels are done up in a figure-of-eight design at 5-foot intervals and then "thrown" into a circular shape. The method of "throwing" a tape does not lend itself to a written description. Hence, the surveyor should learn this procedure from one who is experienced.

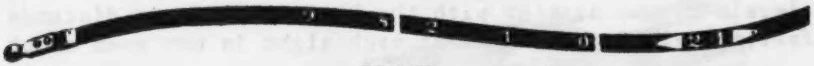
Metallic or woven tapes are made of cloth with fine brass wire woven into them to minimize stretching. They usually come in lengths of 50 feet but may be obtained in 25-foot or 100-foot lengths. Measurements not requiring a high degree of accuracy, such as dimensions of existing bridge openings, short distances in taking cross sections or topography, and distances for stripcropping and orchard terracing layouts, usually are made with a metallic tape.



RIVETED TABS



BABBITT METAL BOSSES



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(ILLUSTRATIONS COURTESY K & E CO.)

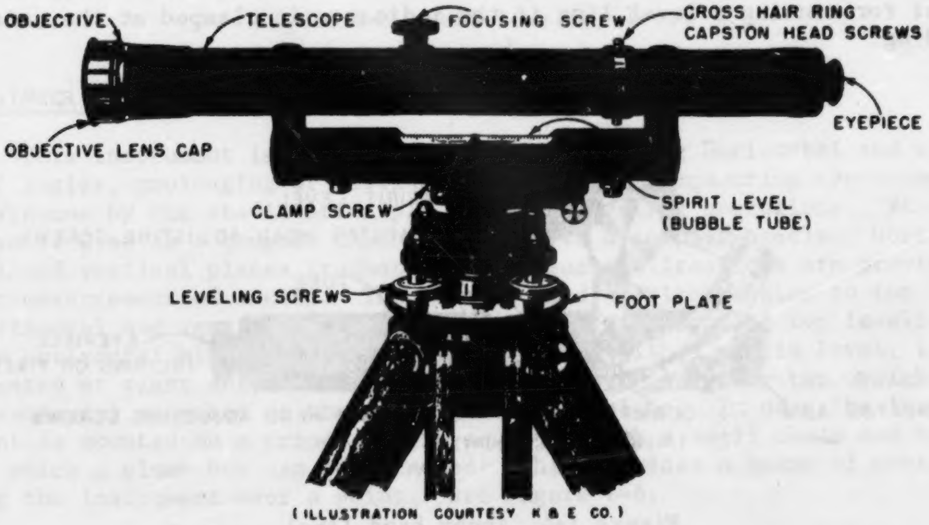
Figure 1-1 Steel tape markings

LEVELS

The types of levels commonly used include the engineer's wye and dumpy levels, and the two hand levels, the Locke and the Abney. Also, increasing use is being made of the self-leveling level.

Dumpy Level

The dumpy level, Figure 1-2, because of its sturdiness, convenience, and stability of adjustment, has largely superseded the wye level and, therefore, it is the only engineer's level discussed in this chapter.

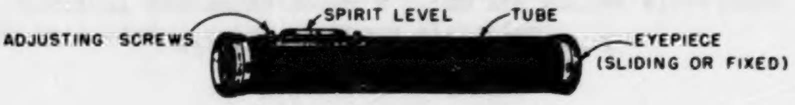

OBJECTIVE
TELESCOPE
FOCUSING SCREW
CROSS HAIR RING
CAPSTON HEAD SCREWS
EYEPIECE
OBJECTIVE LENS CAP
CLAMP SCREW
SPIRIT LEVEL
(BUBBLE TUBE)
LEVELING SCREWS
FOOT PLATE

(ILLUSTRATION COURTESY K & E CO.)

Figure 1-2 Engineer's dumpy level

Locke Hand Level

The Locke hand level, Figure 1-3, is used for rough measurements of differences in elevation. It is used by standing erect and sighting through the eyepiece, holding the tube in the hand, and moving the objective end up and down until the image of the spirit level bubble on the mirror is centered on the fixed cross wire. The point where the line of sight in this position strikes the rod or other object is then noted. The vertical distance from the ground to the surveyor's eye is used to determine the height of instrument and other ground elevations. A rough line of levels may be carried with the hand level for a distance of 400 to 500 feet, provided the length of each sight is not over about 50 feet.

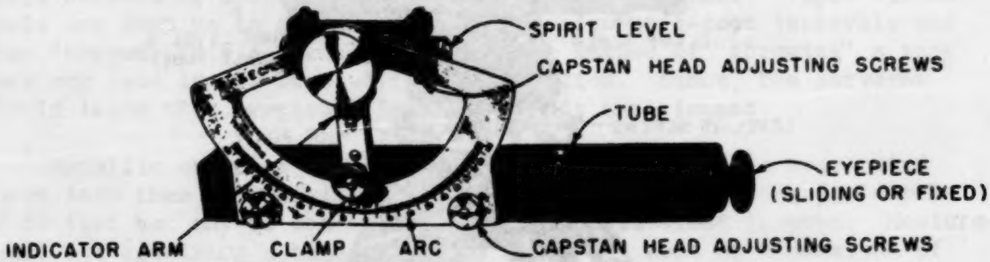

SPIRIT LEVEL
TUBE
ADJUSTING SCREWS
EYEPIECE (SLIDING OR FIXED)

(ILLUSTRATION COURTESY K & E CO.)

Figure 1-3 Locke hand level

Abney Hand Level

The Abney hand level, Figure 1-4, is constructed and used in the same manner as the Locke hand level, except that it has a graduated arc for reading percent of slope. The spirit level is attached to the arc on the Abney level. The user sights through the tube and fixes the line of sight so that it will be parallel to the slope on which it is desired to measure the percent of slope. The indicator is then adjusted with the free hand until the image of the spirit level bubble is centered on the cross wire. The indicator is then clamped and the percent of slope read. The Abney level may be used in the same manner as the Locke hand level for running a level line if the indicator is clamped at the zero reading.

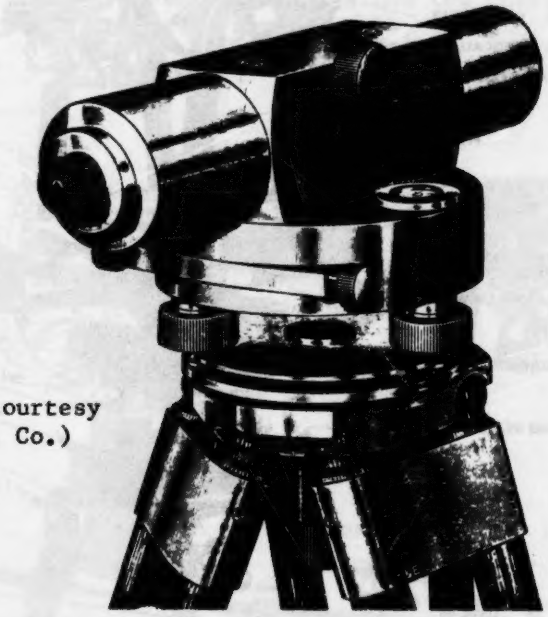

SPIRIT LEVEL
CAPSTAN HEAD ADJUSTING SCREWS
TUBE
EYEPIECE (SLIDING OR FIXED)
INDICATOR ARM
CLAMP
ARC
CAPSTAN HEAD ADJUSTING SCREWS

(ILLUSTRATION COURTESY K & E CO.)

Figure 1-4 Abney hand level

Self-Leveling Level

The self-leveling level automatically levels its line of sight with great accuracy. There is no tubular spirit level and no tilting screw. It levels itself by means of a compensator after the circular spirit level is centered approximately. It is precise as well as simple and quick to operate and can be used for any type level survey. See Figure 1-5.



(Illustrated courtesy of K. & E. Co.)

Figure 1-5 Self-leveling level

ENGINEER'S TRANSIT

This instrument is used primarily for measuring horizontal and vertical angles, prolonging or setting points in line, measuring approximate distances by the stadia principle, and for leveling operations. It can also be used as a compass when equipped with a compass needle. Horizontal and vertical plates graduated in degrees and fractions are provided for measurement of angles. They are mounted at right angles to the horizontal and vertical axis. Spirit levels are provided for leveling the horizontal plates. A telescope, equipped with a spirit level, is mounted at right angles on a horizontal axis supported by two uprights (standards) attached to the upper horizontal plate. In use, the instrument is mounted on a tripod and is equipped with a small chain and hook to which a plumb bob can be attached. This provides a means of centering the instrument over a point. See Figure 1-6.

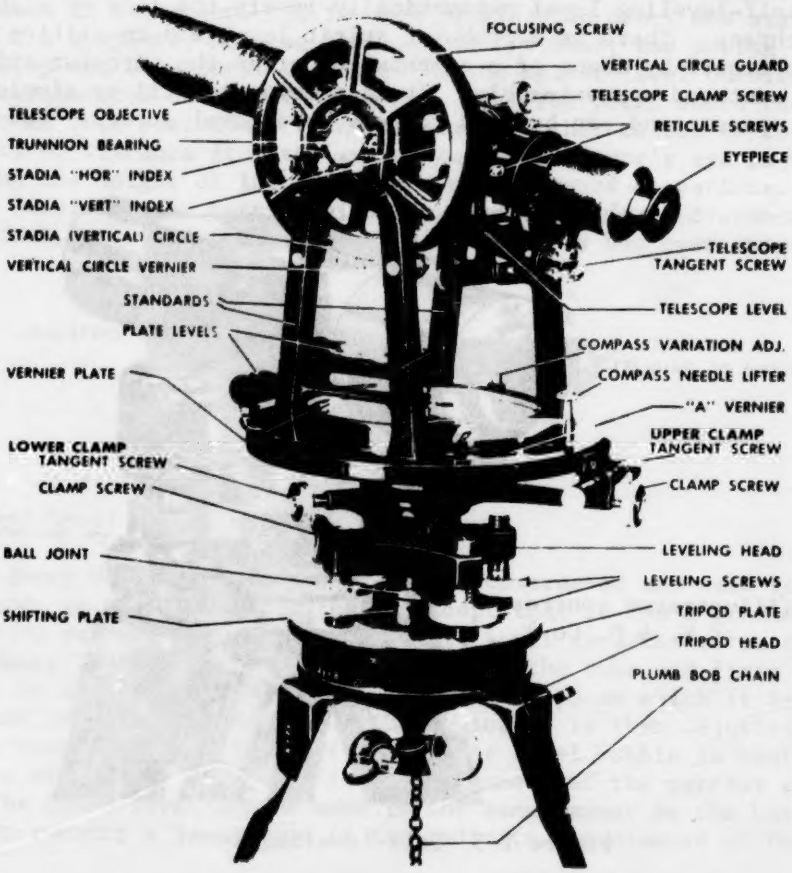

FOCUSING SCREW
VERTICAL CIRCLE GUARD
TELESCOPE CLAMP SCREW
RETICULE SCREWS
EYEPIECE
TELESCOPE OBJECTIVE
TRUNNION BEARING
STADIA "HOR" INDEX
STADIA "VERT" INDEX
STADIA (VERTICAL) CIRCLE
VERTICAL CIRCLE VERNIER
TELESCOPE TANGENT SCREW
STANDARDS
PLATE LEVELS
TELESCOPE LEVEL
COMPASS VARIATION ADJ.
VERNIER PLATE
COMPASS NEEDLE LIFTER
"A" VERNIER
LOWER CLAMP TANGENT SCREW
UPPER CLAMP TANGENT SCREW
CLAMP SCREW
CLAMP SCREW
LEVELING HEAD
BALL JOINT
LEVELING SCREWS
TRIPOD PLATE
SHIFTING PLATE
TRIPOD HEAD
PLUMB BOB CHAIN

Figure 1-6 Engineer's transit

PLANETABLE AND ALIDADE

A drawing board is attached to a tripod in such a manner that it can be leveled, rotated and locked in the position selected. Drawing paper attached to the board allows plotting of the survey data in the field as the survey progresses. See Figure 1-7.

There are two types of alidades - the open sight and the telescopic. The open sight alidade consists of a set of sights mounted on a ruler or straightedge in such a manner that the line of sight is parallel to the edges of the ruler.

The telescopic alidade consists of a telescope mounted on a horizontal axis which is supported by standards attached to the straightedge either directly or by means of a post. The telescope is equipped with a vertical arc and a striding or attached level bubble. In addition, many instruments are equipped with a Beaman stadia arc and a Vernier control bubble. See Figure 1-7.

The planetable and alidade are used most effectively for obtaining detail and topography. Mapping can be done rapidly and a more accurate representation of the terrain can be obtained since the operator can see the form of the ground that he is mapping.

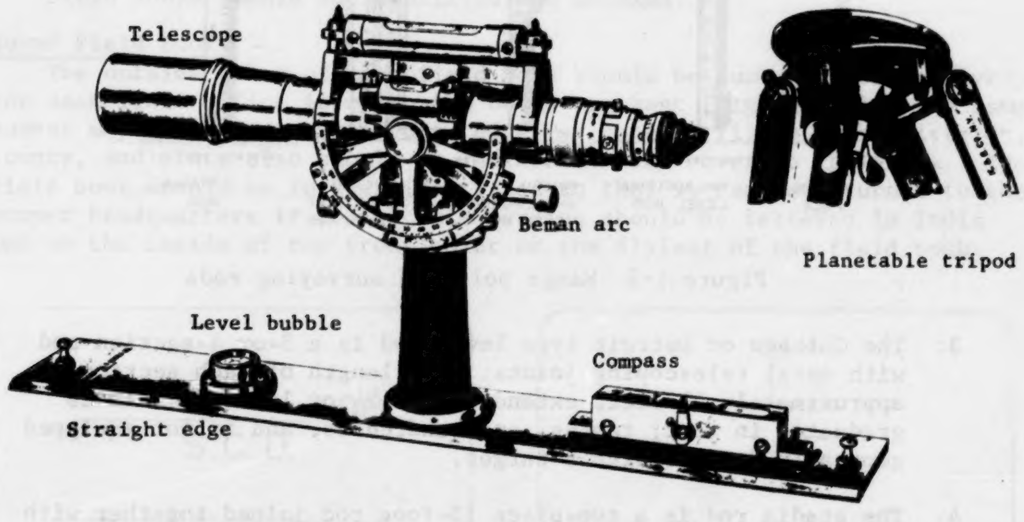


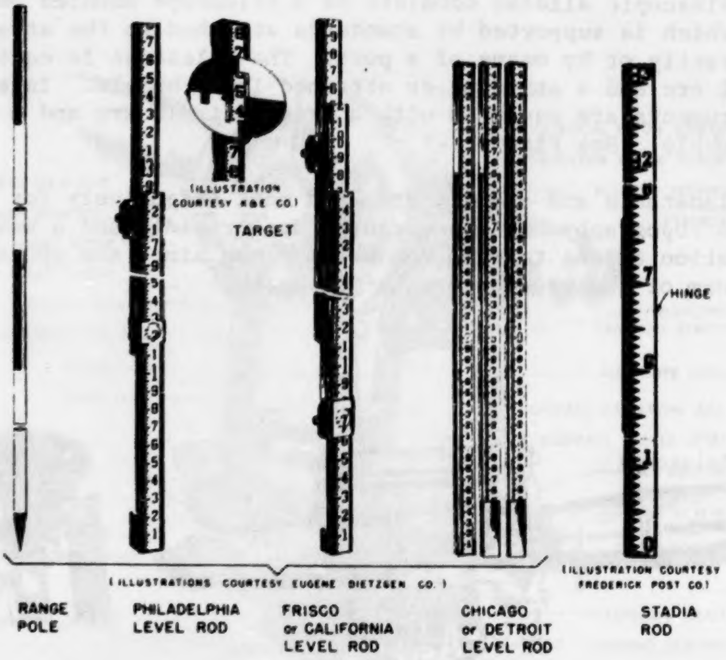
Figure 1-7 Telescopic alidade and planetable tripod

LEVEL RODS AND ACCESSORIES

There are many kinds of level rods and accessories. Those generally used by soil conservation technicians are shown in Figure 1-8.

1. The Philadelphia type level rod is a two-section rod equipped with clamp screws. Its length is approximately 7 feet, extending to 13 feet. It is graduated in feet, tenths, and hundredths. It may be equipped with round, oval, plain, or vernier scale target.

2. The Frisco or California type level rod is a three-section rod equipped with clamp screws. Its length is 4½ feet extending to 12 feet or 5½ feet extending to 15 feet. It is graduated in feet, tenths, and hundredths. This rod is not equipped for use with a target.



(ILLUSTRATION COURTESY K&E CO)

(ILLUSTRATIONS COURTESY EUGENE DIETZGEN CO.)

(ILLUSTRATION COURTESY FREDERICK POST CO)

Figure 1-8 Range pole and surveying rods

3. The Chicago or Detroit type level rod is a 3-or 4-section rod with metal telescoping joints. The length of each section is approximately 4½ feet, extending to 12½ or 16½ feet. It is graduated in feet, tenths, and hundredths, and is not equipped generally for use with a target.

4. The stadia rod is a two-piece 13-foot rod joined together with hinges and with a suitable locking device to insure stability. It has metal shoes on both ends. The face is approximately 3½ inches wide, which is divided into feet and tenths. This type of rod is designed primarily for use in making topographic surveys and is not equipped for use with a target.

5. The range pole is a one- or two-piece pole from 6 to 10 feet in length with alternate feet painted red and white. It is used generally to establish a "line of sight."

FIELD BOOKS

Purpose

Engineering field books are used for the recording of survey notes and layout and construction data. They are valuable documents because of the time and expense involved in obtaining such data. An ordinary field book is worth from $200 to $1,000 or more when it is filled with notes properly recorded, depending upon the type of surveys recorded. Therefore, used field notebooks are nonexpendable property which should be carefully preserved for future use of the data. Losing a field book is a "cardinal sin" to a surveyor. It should not be used for scratch computations or notes which have no permanent value pertaining to engineering surveys.

Types

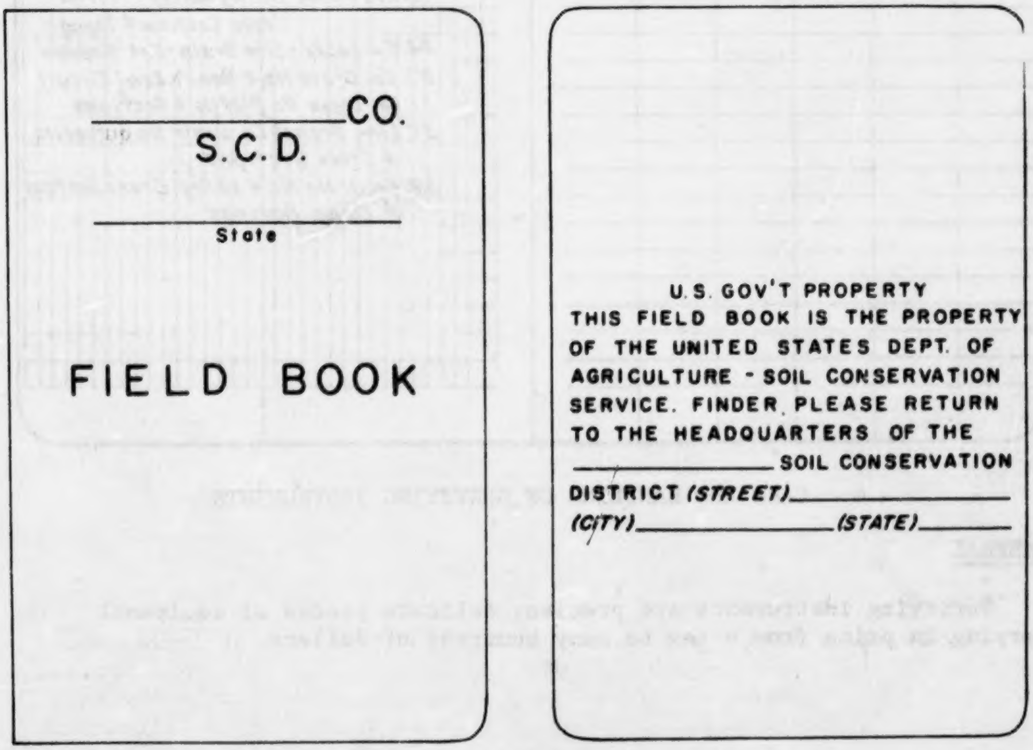
There are two types of field books in general use: The looseleaf, and the bound field book. Bound field books may be either the duplicating or non-duplicating type. The duplicating type produces a carbon copy which can be removed, retaining the original in the book.

Identifying and Indexing

Field books should be identified and indexed.

Bound Field Books

The outside cover of each field book should be numbered consecutively for each field office in which the books are kept (Figure 1-9). The same number may be placed on the bound edge for ease in filing. The district, county, and state also should be lettered on the cover in India ink. Each field book should be further identified so that it can be returned to the proper headquarters if lost. This wording should be lettered in India ink on the inside of the front cover or the flyleaf of the field book.



_____________CO.
S.C.D.
____
State

FIELD BOOK

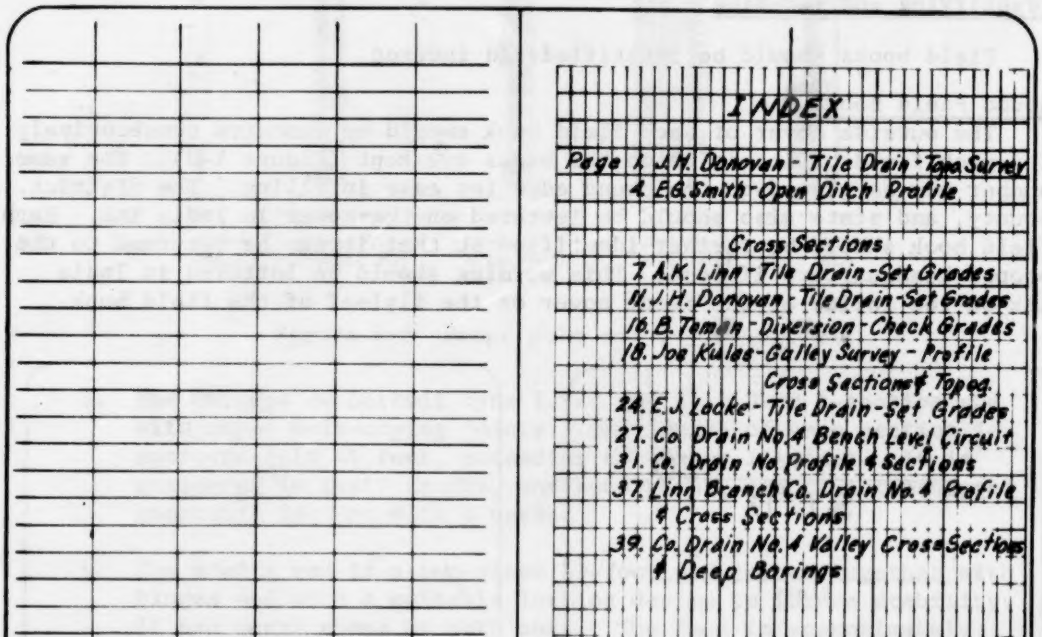
U.S. GOV'T PROPERTY
THIS FIELD BOOK IS THE PROPERTY
OF THE UNITED STATES DEPT. OF
AGRICULTURE - SOIL CONSERVATION
SERVICE. FINDER PLEASE RETURN
TO THE HEADQUARTERS OF THE
_____________ SOIL CONSERVATION
DISTRICT *(STREET)*_____________
*(CITY)*_____________ *(STATE)*_______

Figure 1-9. Field book identification

The first four pages of the bound book should be reserved for the index (Figure 1-10). The following pages should be numbered consecutively in the upper right-hand corner of each page. Note that "page" in a field book means the combination of the six ruled columns on the left and the cross section paper on the right.

Looseleaf Field Books

Looseleaf field books are commonly used in soil conservation work, but care has to be taken to insure proper identification and filing. All pages of a looseleaf field book pertaining to a particular job should be properly identified, indexed, stapled together and filed in accordance with State instructions.



INDEX

Page 1. J.H. Donovan - Tile Drain - Topo Survey
4. E.G. Smith - Open Ditch Profile

Cross Sections
7. A.K. Linn - Tile Drain - Set Grades
11. J.H. Donovan - Tile Drain - Set Grades
16. B. Toman - Diversion - Check Grades
18. Joe Kulas - Galley Survey - Profile
Cross Sections & Topog.
24. E.J. Locke - Tile Drain - Set Grades
27. Co. Drain No. 4 Bench Level Circuit
31. Co. Drain No. Profile & Sections
37. Linn Branch Co. Drain No. 4 Profile
& Cross Sections
39. Co. Drain No. 4 Valley Cross Sections
& Deep Borings

4. CARE AND HANDLING OF SURVEYING INSTRUMENTS

GENERAL

Surveying instruments are precise, delicate pieces of equipment varying in price from a few to many hundreds of dollars.

Proper care and protection is necessary in order to keep the instruments in accurate adjustment and operating condition. Certain procedures and precautions must be observed in using surveying instruments to prevent needless damage or unnecessary wear and to reduce the occurrence of accidents. Instruments in good condition and properly adjusted are essential to speed and accuracy in fieldwork.

TAPES

Steel tapes are broken easily if not properly handled. It should not be jerked needlessly,stepped on, bent around sharp corners or vehicles allowed to run over it. The most common cause of a broken tape is pulling on it when there is a loop or kink in it. Slight deformations caused by kinking should be straightened carefully with the fingers.

Insofar as possible, avoid dragging the tape with markings face down as abrasive action will remove markings. In spite of reasonable care, tapes will be broken occasionally. Each headquarters using steel tapes regularly should have a tape repair kit.

After each day's use, steel and metallic tapes should be wiped dry and clean with a clean cloth. Steel tapes should be given a light covering of oil by wiping with an oily cloth after cleaning.

TRANSPORTING LEVEL OR TRANSIT AND ROD

Surveying instruments should be carried in the instrument case in the cab of the vehicle, preferably on the floor or in a well-padded compartment located approximately halfway between the front and rear axles. Level rods should be in cases and carried where they will be protected from weather and from material being piled on top of or against them. Tripods should be similarly protected from damage and the weather.

MOUNTING LEVEL OR TRANSIT ON TRIPOD

The first step in mounting the level or transit is to set up the tripod. The tripod cap should be removed and placed in the instrument box to prevent it from being lost. Dust and sand particles should be blown from the tripod head before screwing on the instrument. The wing nuts on the tripod should be tightened just enough so that when a tripod leg is elevated it will drop gradually of its own weight.

The instrument should be carefully removed from the case. It is best to place the fingers beneath the horizontal bar of a level or the plate of a transit when removing it from the case. See that the instrument is attached securely to the tripod. When screwing the instrument base on the tripod, it should be turned first in the reverse direction until a slight jar is felt, indicating that the threads are engaged properly. Then it should be screwed on slowly until it refuses to turn farther, but not so tightly that it will be difficult to unscrew when the instrument is dismounted.

The objective lens cap should be removed and placed in the instrument case for safekeeping, and the sunshade attached to the telescope. The sunshade, attached with a slight twisting movement, should be used regardless of the weather.

CARRYING THE INSTRUMENT

The compass needle lifter on the transit should be tightened any time the compass is not in use.

Usually the instrument is carried to the field on the shoulder. But in passing through doors, woods, or brush the technician should hold the instrument head close to the front of his body. Little damage will be done to tripod legs if they strike the side of a door jamb or tree as compared to the damage to the instrument head if similarly hit.

Before crossing a fence, set the instrument firmly in a location where it will be safe and may be reached easily from the other side. Do not allow the instrument to fall.

CLEANING AND STORAGE OF EQUIPMENT

Always return the instrument to the case when returning from the field. Before placing the instrument in the case loosen the lower clamp screw (transit) and replace the object glass cap on the telescope. Return the sunshade to the case. After placing the instrument into the case tighten the transit telescope clamp screw. The lid should close freely and easily. If it does not, the instrument is not properly placed on the pads. Never force the lid; look for the cause of the obstruction.

In setting up the instrument indoors for inspection or cleaning be careful that the tripod does not spread and drop the instrument on the floor. Spreading of the legs can be prevented by tying a cord around and through the openings in the legs. Never leave an instrument standing unguarded in the field or indoors.

Dust and grime which collect on the outside moving parts must be carefully removed from surveying instruments. A light machine oil may be used for softening grime on leveling screws, footplate threads, clamp screws, and other outside parts which may be cleaned without dismantling the instrument. A drop of oil may be placed on the leveling screws which are then screwed back and forth to bring out dirt and grime. They should be wiped off with a clean cloth and the process repeated until the oil comes through clean. It is better not to leave any oil on the moving parts of the instrument. They do not need lubrication. Oil catches and holds dust which abrades the soft brass parts.

Do not remove or rub the lenses of the telescope. These lenses are made of soft glass that scratches easily. They should be dusted with a clean, soft, camel's hair brush, or wiped very carefully with a clean, soft cloth to avoid scratching or marring the polished surfaces.

Equipment should be stored in a dry place. Level rods, stadia rods, and tripods must be stored in such a manner that they will not warp or become otherwise damaged. They should be fully protected from the elements when not in use. The tripod screws should be loosened. It is better to store level rods flat on at least three supports. Never leave a rod leaning against a wall for long periods. They warp from their own weight. It is satisfactory to store them in a plumb position. A coat of varnish should be maintained on the wooden parts at all times.

5. CHECKING INSTRUMENTS FOR ADJUSTMENT

GENERAL

Engineering surveys cannot be made with an acceptable degree of accuracy unless the instrument is kept in adjustment. Untrained personnel should not attempt to adjust instruments. Adjustment and training in the adjustment of instruments are primarily the responsibility of an engineer. However, it is essential that all personnel using surveying instruments be familiar with the procedure for checking and adjusting an instrument. The adjustment of an instrument should be checked frequently. An adjustment record should be attached inside the lid of each instrument case.

HAND LEVEL

To adjust a hand level hold it alongside an engineer's level that has been leveled and sighted on some well-defined point. The line of sight of the hand level should strike the same point when the bubble is centered. If this condition is not satisfied, an adjustment should be made.

Locke

Adjust by means of the screw at one end of the level tube, which moves the cross-wire defining the line of sight.

Abney

Adjust by raising or lowering one end of the level tube until the bubble is centered, the index having first been set at zero on the graduated arc. The principle of the two-peg method of adjustment, as described in this chapter for the engineer's level, may also be used.

DUMPY LEVEL

General

The dumpy level is in adjustment when: 1) The horizontal crosshair is truly horizontal with the instrument leveled; 2) the axis of the bubble tube is perpendicular to the vertical axis; and 3) the axis of the bubble tube and the line of sight are parallel. Before adjusting, check for parallax as described for transit.

Adjustment of Crosshairs

To make the horizontal crosshair lie in a plane perpendicular to the vertical axis, set up level and sight a definite fixed point in the field of view. Next, turn the telescope about the vertical axis. If the point appears to travel along the crosshair, no adjustment is necessary. If a point leaves the crosshair, loosen the capstan screws holding the crosshair ring in place. Turn ring with pressure from fingers or tapping with a pencil and retest until the point remains on the crosshair as the telescope is rotated. When capstan screw is retightened adjustment is completed. See similar test for transit.

Adjustment of Bubble Tube

To make the axis of the bubble tube perpendicular to the vertical axis, center the bubble over both pairs of leveling screws and then bring it to center exactly over one pair of screws. If telescope is rotated end for end over the same pair of screws, the bubble will remain centered if in adjustment. If not, the amount of movement away from center is double the error of adjustment. Bring the bubble back halfway with the adjusting screw at one end of the bubble tube. The bubble, then brought back to center with the leveling screws, should remain centered after reversal of the telescope by rotation.

Direct or "Peg" Adjustment

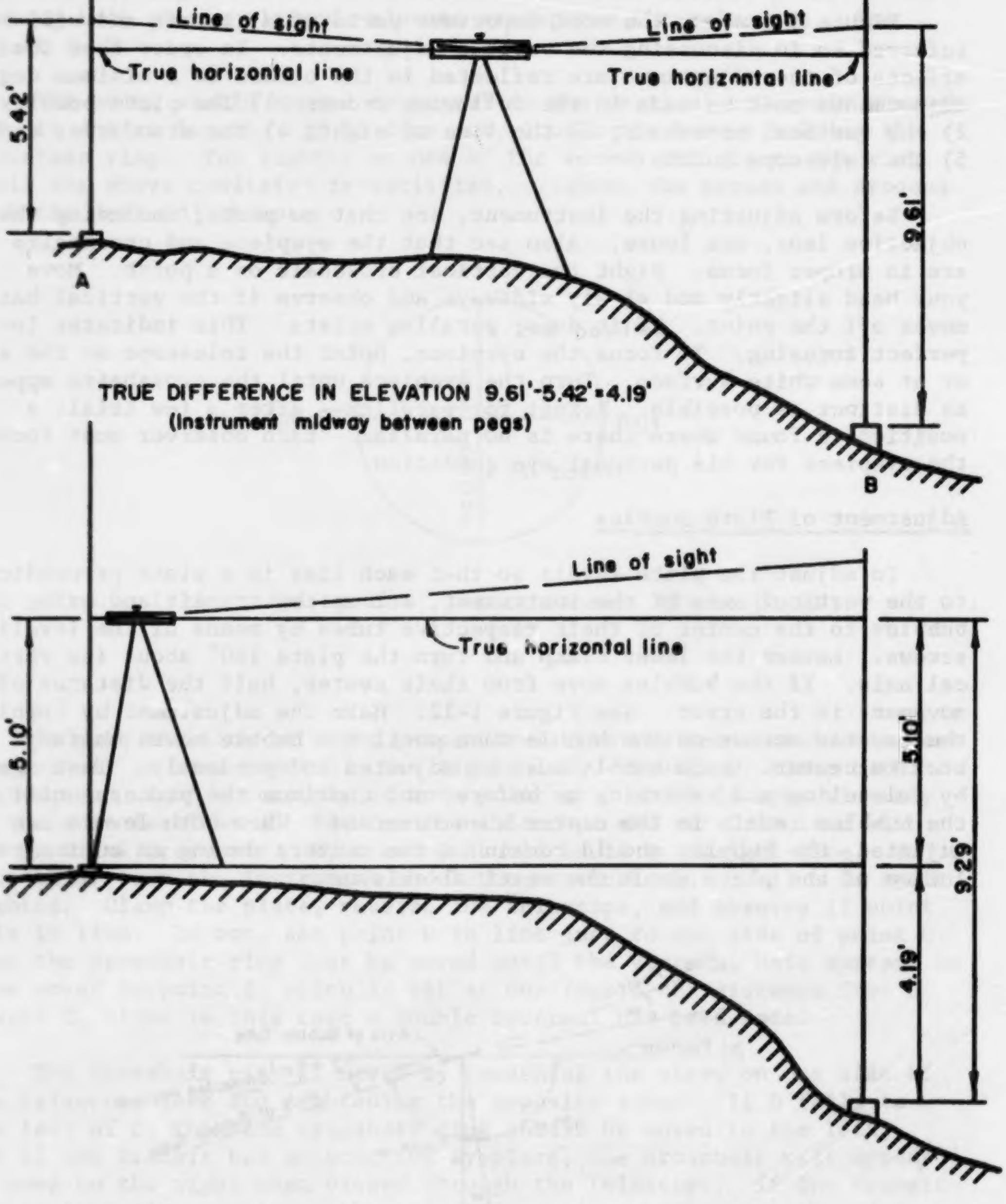
To make the line of sight parallel to the axis of the bubble, perform the two-peg test. Set two pegs or stakes 200 or 300 feet apart. Set the instrument midway between them. Take a rod reading on each peg with the telescope bubble centered at each reading. See Figure 1-11. The difference in the two rod readings (4.19 feet) gives the true difference in elevation between the pegs.

Next, set the instrument at A, preferably the high peg, and read the rod while it is held against or within a half-inch of the eyepiece. Note where the center of the eyepiece touches the rod. It may be preferred to take this reading backwards through the telescope. This reading, plus or minus the above difference, gives the true reading at B (9.29 feet) which makes the line of sight horizontal. With the horizontal crosshair on this reading on the rod at B, the line of sight is parallel to the axis of the bubble if the bubble is in the center of the tube. If it is out of adjustment, keep bubble tube centered and move the horizontal crosshair until the line of sight intercepts the true reading on the rod at B.

TRANSIT

General

A transit is in adjustment when: 1) The axis of the plate bubbles are perpendicular to the vertical axis; 2) the vertical hair is perpendicular to the horizontal axis; 3) the line of site is perpendicular to


Line of sight
True horizontal line
Line of sight
True horizontal line
5.42'
9.61'
A
B
Line of sight
True horizontal line
5.10'
5.10'
9.29'
4.19'

TRUE DIFFERENCE IN ELEVATION 9.61'-5.42'=4.19'
(Instrument midway between pegs)

Figure 1-11. Adjustment of level (two-peg method)

the horizontal axis; 4) the standards are at the same height; 5) the line of sight and the axis of the telescope level are parallel; and 6) the telescope is level with zeros of the vertical arc and vernier coinciding.

Figure 1-6 shows the most important parts of a transit and will be referred to in discussing the various adjustments. In order that the effects of one adjustment are reflected in the others to a minimum degree, adjustments must be made in the following order: 1) The plate bubbles; 2) the vertical crosshair; 3) the line of sight; 4) the standards; and 5) the telescope bubble.

Before adjusting the instrument, see that no parts, including the objective lens, are loose. Also see that the eyepiece and crosshairs are in proper focus. Sight the vertical crosshair on a point. Move your head slightly and slowly sideways and observe if the vertical hair moves off the point. If it does, parallax exists. This indicates imperfect focusing. To focus the eyepiece, point the telescope at the sky or at some white surface. Turn the eyepiece until the crosshairs appear as distinct as possible. Retest for parallax-- after a few trials a position is found where there is no parallax. Each observer must focus the eyepiece for his personal eye condition.

Adjustment of Plate Bubbles

To adjust the plate levels so that each lies in a plane perpendicular to the vertical axis of the instrument, set up the transit and bring the bubbles to the center of their respective tubes by means of the leveling screws. Loosen the lower clamp and turn the plate 180° about its vertical axis. If the bubbles move from their center, half the distance of movement is the error. See Figure 1-12. Make the adjustment by turning the capstan screws on the bubble tube until the bubble moves halfway back to center. Each bubble must be adjusted independently. Test again by releveling and reversing as before, and continue the process until the bubbles remain in the center when reversed. When both levels are adjusted, the bubbles should remain in the centers during an entire revolution of the plate about the vertical axis.

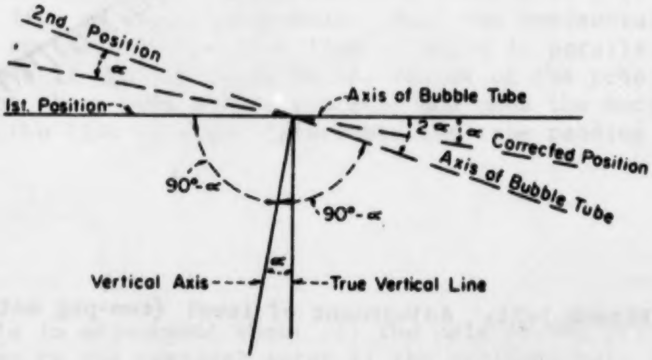


Figure 1-12 Adjustment of the plate bubbles

Adjustment of Crosshairs

To put the vertical crosshair in a plane perpendicular to the horizontal axis, sight the vertical hair on some well-defined point. Then leaving both plates clamped, elevate or depress the telescope. See Figure 1-13.

The point should appear to travel on the vertical crosshair throughout its entire length. If it does not, loosen the screws holding the crosshair ring. Tap lightly on one of the screws and rotate the ring until the above condition is satisfied. Tighten the screws and proceed with the next adjustment.

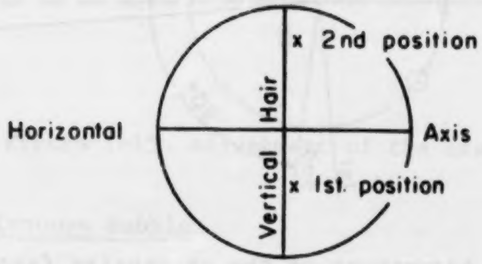


Figure 1-13. Adjustment of the crosshairs (first part)

To make the line of sight perpendicular to the horizontal axis, set the transit at some point A. See Figure 1-14. Level up, clamp both plates, and sight accurately on some point at B which is approximately at the same level as A. Reverse the telescope and set C in line with the vertical crosshair. B, A and C should be in a straight line. To test this, turn the instrument about the vertical axis until B is again sighted. Clamp the plate, reverse the telescope, and observe if point C is in line. If not, set point D in line just to one side of point C. Then the crosshair ring must be moved until the vertical hair appears to have moved to point E, which is set at one-fourth the distance from D toward C, since in this case a double reversal has been made.

The crosshair ring is moved by loosening the screw on one side of the telescope tube and tightening the opposite screw. If D falls to the left of C, then the crosshair ring should be moved to the left; but if the transit has an erecting eyepiece, the crosshair will appear to move to the right when viewed through the telescope. If the transit has an inverting eyepiece, the crosshair appears to move in the same direction in which the crosshair is actually moved.

The process of reversal should be repeated until no further adjustment is required. When finally adjusted, the screws should hold the ring firmly but without straining it.

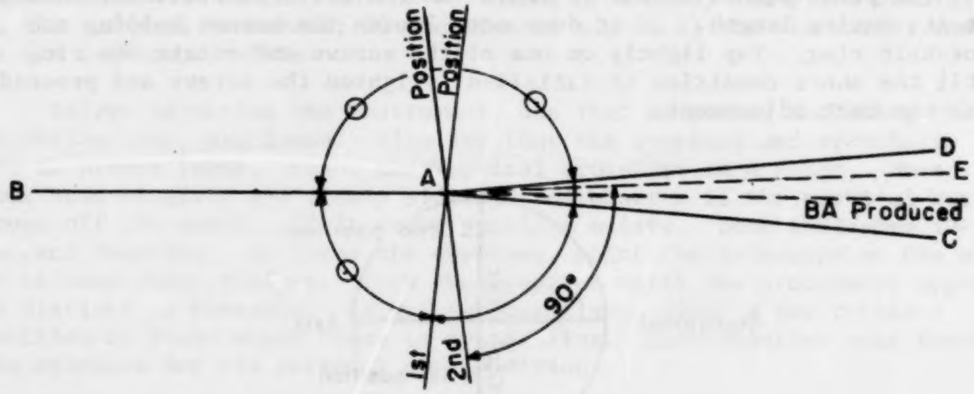


Figure 1-14. Adjustment of the crosshairs (second part)

Adjustment of Standards

To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument, set up the transit and sight the vertical crosshair on a high point A, such as the top of a church steeple. See Figure 1-15. Lower the telescope and set a point B in line, on the same level as the telescope. Reverse the telescope, turn the instrument about its vertical axis, and sight on B. Raise the telescope until the point A is visible and see if the crosshairs fall on A. If not, note point C in line and at the same height as A. Then half the distance from C to A is the error of adjustment.

Loosen the screws in the pivot cap and raise or lower the adjustable end of the horizontal axis by means of the capstan-headed screw under the end of the axis. Repeat the test until the high and the low points are both on the crosshair in either the direct or the reversed positions of the transit. The adjusting screw should be brought into position by a right-hand turn, otherwise the block on which the horizontal axis rests may stick and not follow the screw. The cap screws should then be tightened just enough to avoid looseness of the bearing.

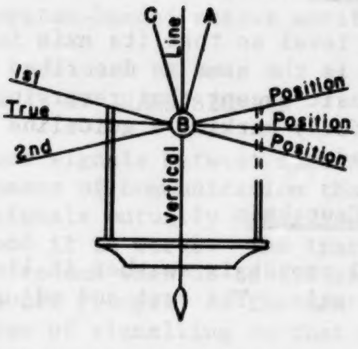


Figure 1-15 Adjustment of the standards

Adjustment of Telescope Bubble

To make the line of sight parallel to the axis of the bubble, make the peg test as described for the dumpy level. See Figure 1-11. If the telescope bubble is out of adjustment, raise or lower one end of the telescope bubble tube by turning the capstan nut until the telescope bubble is centered. Note the true reading at B. After this adjustment has been made, the vertical arc and the vernier zero-line should be examined also to see whether they coincide when the telescope bubble is in the center of the tube. If not, the vernier may be moved by loosening the capstan-headed screws which hold the vernier to the standard. The zero lines are brought together and the screws tightened.

PLANETABLE AND TELESCOPIC ALIDADE

General

Adjustments of the telescopic alidade require no principles of adjustment other than those for the transit or level. Survey work done with the planetable and the telescopic alidade is not required to be as precise as when the work is done with the transit; therefore, the adjustments need not be as refined.

Since the telescope is not reversed in a vertical arc, no appreciable error is caused because of lack of perpendicularity between the line of sight and the horizontal axis, or through lack or parallelism of the line of sight with the edge of the ruler. It can also be assumed without appreciable error that the edges of the ruler are straight and parallel and that the horizontal axis is parallel to the surface of the ruler.

Adjustment of Control Level

Adjust the control level so that its axis is parallel to the ruler. The test and correction is the same as described for adjustment of the plate levels of the transit except that reversing of the plate or ruler is accomplished by carefully marking a guideline on the planetable sheet. The board is not reversed.

Adjustment of Vertical Crosshair

Adjust the vertical crosshair so that it lies in a plane perpendicular to the horizontal axis. The test and adjustment is the same as for the transit.

Adjustment of Telescope Level

Adjust the telescope level so that its axis is parallel to the line of sight. The test and correction is the same as described for adjustment of the telescope level on the transit.

If the alidade is one in which the telescope can be rotated about its axis in a sleeve, the two following adjustments should be used.

First, make the line of sight coincide with the axis of the telescope sleeve. In making the test the intersection of the crosshairs should be sighted on some well-defined point and the telescope carefully rotated through 180°. Generally the rotation is limited by a shoulder and lug. If the intersection of the crosshairs stays on the point the line of sight coincides with the axis of the telescope sleeve

Second, make the axis of the striding level so that it is parallel to the telescope sleeve and therefore parallel to the line of sight. In making the test the striding level is placed on the telescope and the bubble is brought to the center of the level tube. The striding level is then carefully removed and turned end for end and replaced on the telescope barrel. If the bubble returns to the center of the tube the level is in adjustment. If the bubble is not centered, it should be brought back one-half of the displacement by means of the adjusting screw on one end of the bubble tube. The bubble should then be brought to the center by means of the tangent screw and the test repeated.

Adjustment of Vernier

Adjust the vernier to read zero when the line of sight is horizontal. This adjustment is the same as described for the transit under "Adjustment of Telescope Bubble".

Adjust the auxiliary level on the vernier arm so that its axis is parallel to the axis of the telescope when the vernier reads zero. The telescope bubble should be brought to the center of its tube and the vernier moved by means of the tangent screw until it reads zero. If the auxiliary level on the vernier arm is not centered, it should be moved by means of the capstan-headed screws until it is in the center of the tube.

6. HAND SIGNALS

A good system of hand signals between members of a surveying party makes a more efficient means of communication than is possible by word of mouth. Any code of signals mutually understood by the instrumentman and the rodman is good if it works. The instrumentman should be prompt in signalling the rodman when he is finished with the "shot" so that the rodman can move off promptly to the next point. It is also desirable to have a system of signalling so that numbers can be transmitted from rodman to instrumentman or vice versa.

The code of signals illustrated in Figures 1-16 and 1-17 is suggested. This code may be enlarged upon or altered to suit the needs of the job. A definite code should, however, be determined and mutually understood in order to speed up the job.

7. SURVEY NOTES AND SYMBOLS

Field notes are the record of a survey, with data recorded in such form that they can be interpreted readily by anyone having knowledge of surveying. Notes should identify the survey by title, including location and purpose, identification of survey party members and duties, date, and weather conditions. Notes should be recorded in a field notebook at the time work is done and not left to memory or later recopied from temporary notes. All data pertaining to one survey or project should be entered in the same field book or series of field books. Books should be identified and indexed as shown in Figures 1-9 and 1-10 before recording notes.

Notes consist of numerical data, explanatory statements, and sketches. Entries should be clear, concise and legible. The form in which notes are recorded varies with different kinds of surveys, such as bench level circuits, profiles and cross sections, transit-traverses, etc. However, a uniform system for each kind should be followed insofar as possible. Sample forms of field notes are illustrated throughout this chapter.

Sketches in field notes are important in conveying information and correct impressions to others plotting data or using the information in engineering design. Sketches should be drawn approximately to scale, using standard SCS mapping symbols. Some of the more commonly used symbols are shown in Figures 1-18 and 1-19.

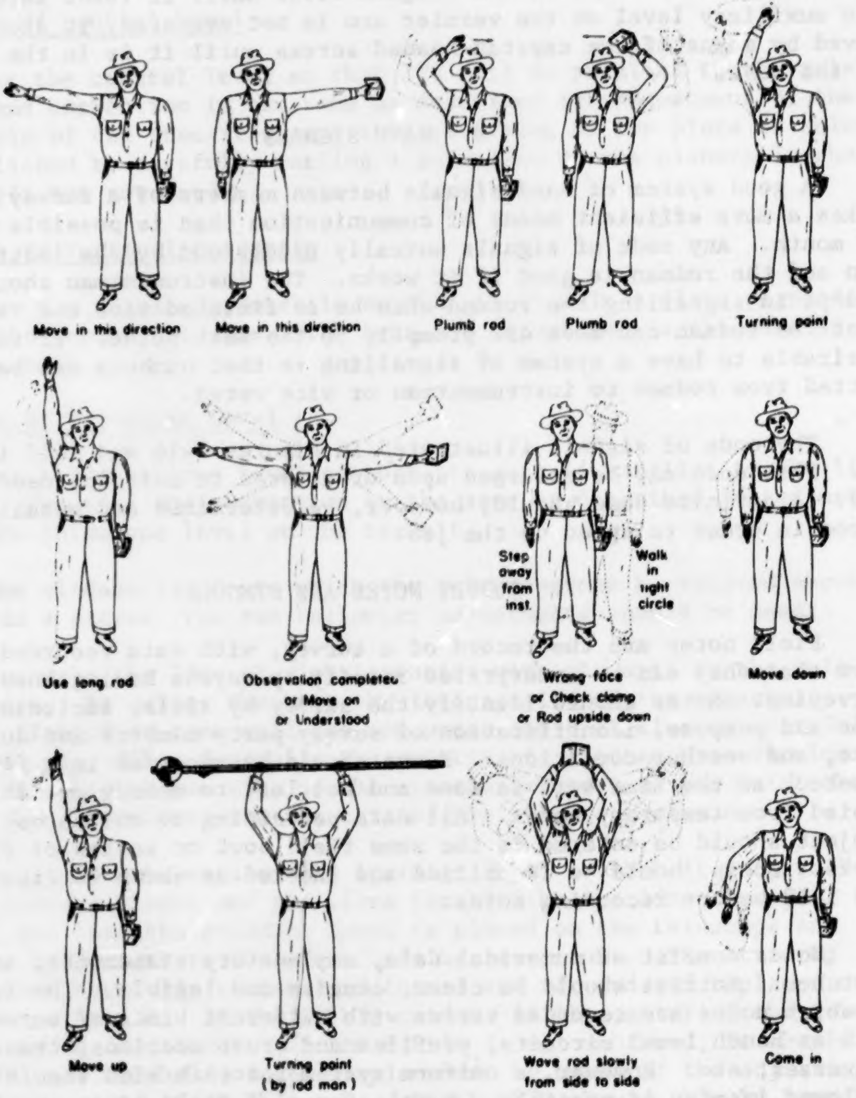
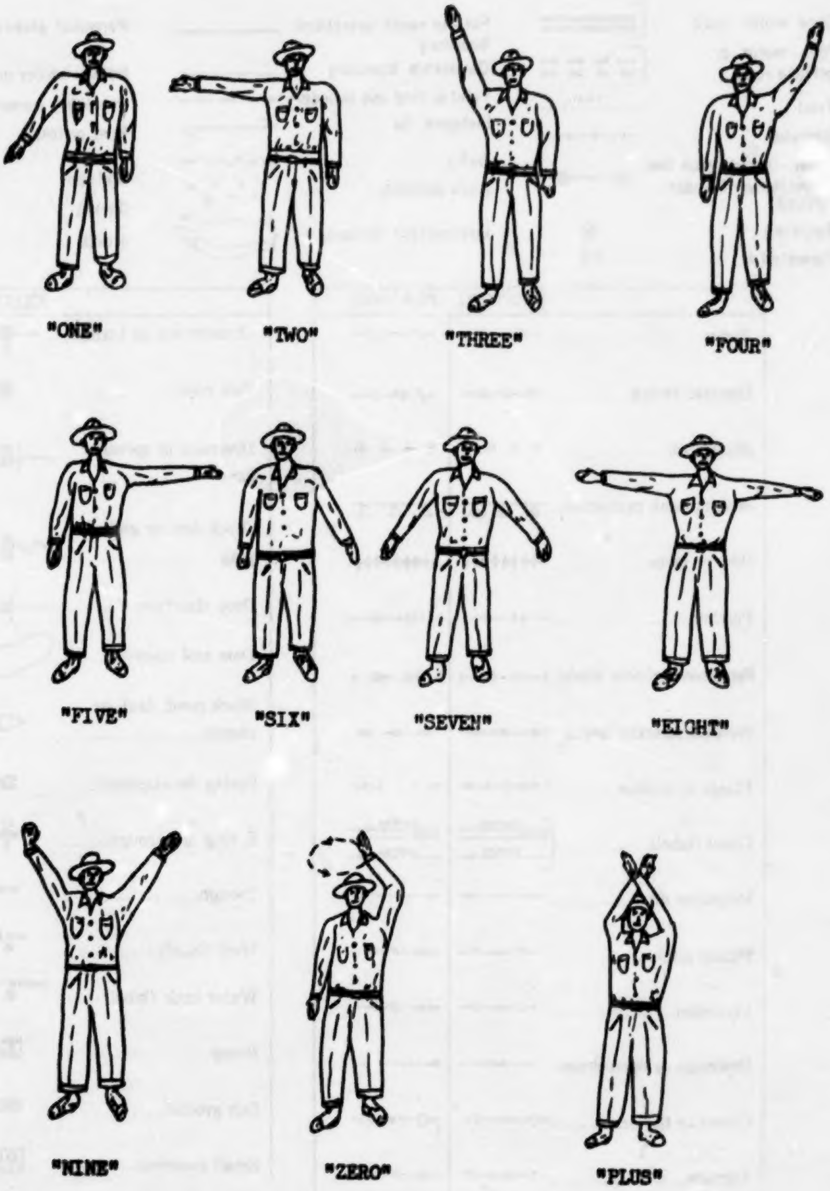

Move in this direction
Move in this direction
Plumb rod
Plumb rod
Turning point
Use long rod
Observation completed or Move on or Understood
Step away from inst.
Walk in right circle
Wrong face or Check clamp or Rod upside down
Move down
Move up
Turning point (by rod man)
Wave rod slowly from side to side
Come in

Figure 1-16 Code of hand signals (instructions)


"ONE" "TWO" "THREE" "FOUR"

"FIVE" "SIX" "SEVEN" "EIGHT"

"NINE" "ZERO" "PLUS"

Figure 1-17 Code of hand signals (numbers)

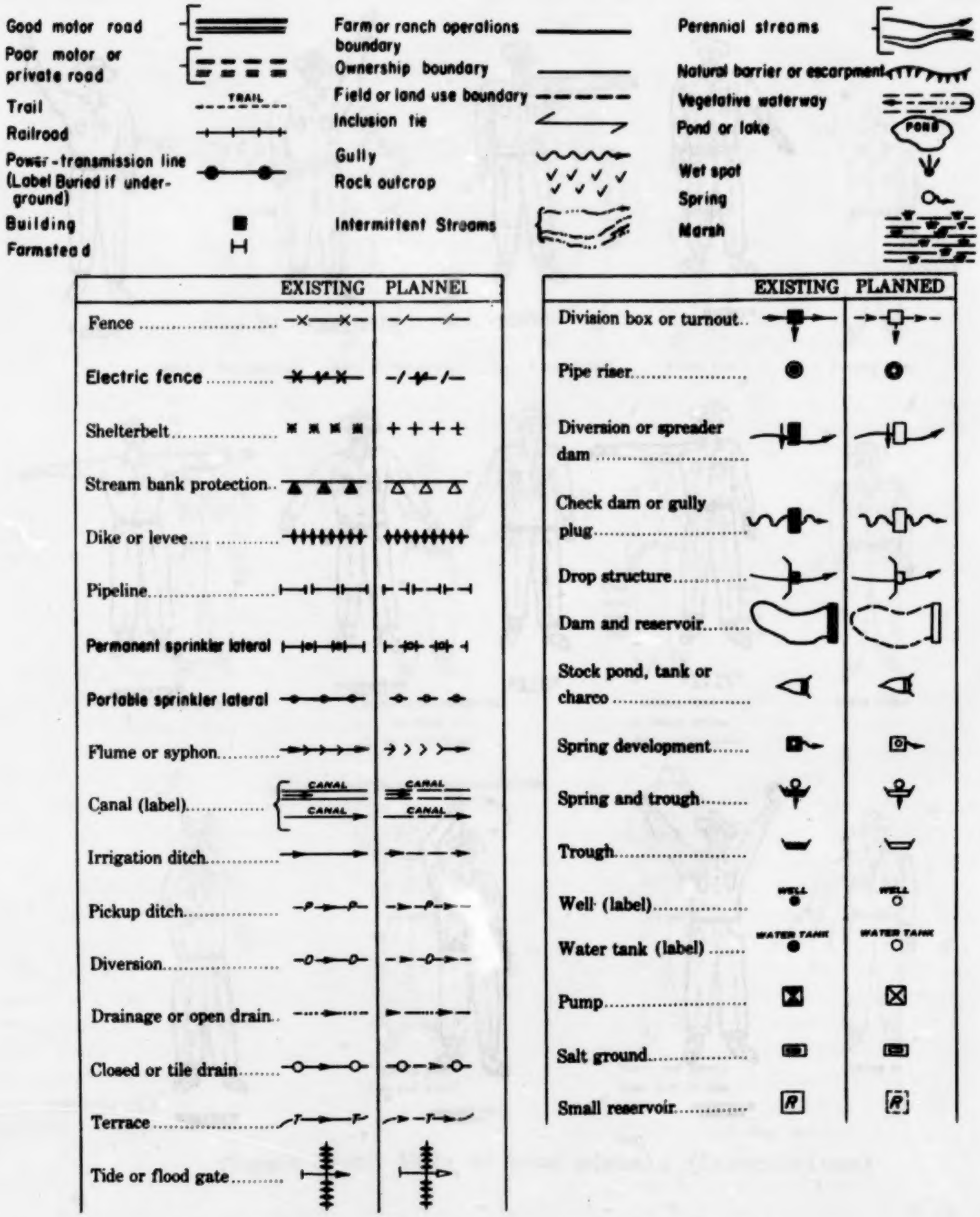
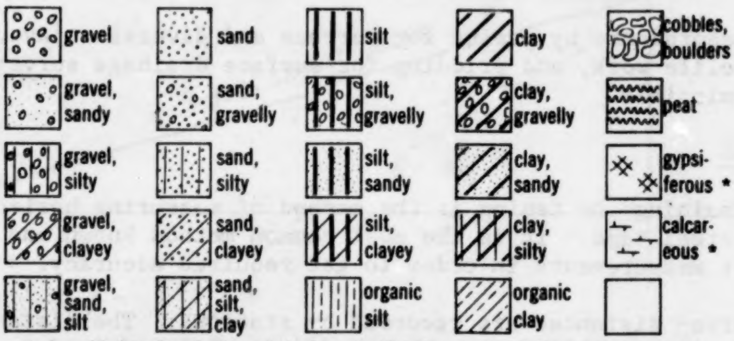

Good motor road
Poor motor or private road
Trail
TRAIL
Railroad
Power-transmission line (Label Buried if underground)
Building
Farmstead
Farm or ranch operations boundary
Ownership boundary
Field or land use boundary
Inclusion tie
Gully
Rock outcrop
Intermittent Streams
Perennial streams
Natural barrier or escarpment
Vegetative waterway
Pond or lake
POND
Wet spot
Spring
Marsh
EXISTING
PLANNED
Fence
Electric fence
Shelterbelt
Stream bank protection
Dike or levee
Pipeline
Permanent sprinkler lateral
Portable sprinkler lateral
Flume or syphon
Canal (label)
CANAL
Irrigation ditch
Pickup ditch
Diversion
Drainage or open drain
Closed or tile drain
Terrace
Tide or flood gate
EXISTING
PLANNED
Division box or turnout
Pipe riser
Diversion or spreader dam
Check dam or gully plug
Drop structure
Dam and reservoir
Stock pond, tank or charco
Spring development
Spring and trough
Trough
Well (label)
WELL
Water tank (label)
WATER TANK
Pump
Salt ground
Small reservoir
R

Figure 1-18 Symbols for soil and water conservation engineering maps and drawings

UNIFIED SOIL CLASSIFICATION SYSTEM SYMBOLS

GW	Well graded gravels; gravel-sand mixtures
GP	Poorly graded gravels
GM	Silty gravels; gravel-sand-silt mixtures
GC	Clayey gravels; gravel-sand-clay mixtures
SW	Well graded sands; sand-gravel mixtures
SP	Poorly graded sands
SM	Silty sand
SC	Clayey sands; sand-clay mixtures
ML	Silts; silty, v. fine sands; sandy or clayey silts
CL	Clays of low to medium plasticity; silty, sandy or gravelly clays
CH	Inorganic clays of high plasticity; fat clays
MH	Elastic silts; micaceous or diatomaceous silts
OL	Organic silts and organic silty clays of low plasticity
OH	Organic clays of medium to high plasticity

UNCONSOLIDATED MATERIALS


gravel
sand
silt
clay
cobbles, boulders
gravel, sandy
sand, gravelly
silt, gravelly
clay, gravelly
peat
gravel, silty
sand, silty
silt, sandy
clay, sandy
gypsiferous *
gravel, clayey
sand, clayey
silt, clayey
clay, silty
calcareous *
gravel, sand, silt
sand, silt, clay
organic silt
organic clay

* to be added to Standard Symbol when significant amounts of dispersed gypsum or calcified zones are present in the section.

Figure 1-19 Soil symbols for soil and water conservation engineering maps and drainage

8. MEASUREMENT OF HORIZONTAL DISTANCES

Pacing, chaining, and stadia are used for measuring horizontal distances.

PACING

Pacing may be used for approximate measurement when an error as large as 2 feet per hundred feet is permissible. Measurement by pacing consists of counting the number of steps between two points and multiplying the number by a predetermined "pace factor". Pace factors will vary between individuals. Each person should determine his individual pace factor while walking his natural stride.

Actually, the pace factor for each individual is the average distance in feet per step. It can be determined best by pacing a measured distance (usually 500 feet) several times. It should be paced enough times to make certain the number of paces for the distance does not vary over 2 or 3. The "pace factor" then would be the distance in feet divided by the number of paces. The "pace factor" may vary with the roughness and slope of the ground. Adjustments should be made to take care of these variations.

Some people prefer to use a stride in place of a pace. It consists of 2 paces, so the "stride factor" would be two times the "pace factor".

Measurements by pacing for terrace and diversion layouts, preliminary profile work, and gridding for surface drainage surveys generally are permissible.

CHAINING

"Chaining" or taping is the method of measuring horizontal distances with a steel tape. It is the most common method known and should be used for most measurements in order to get required accuracy.

Survey distances are recorded by stations. The distances between full stations is 100 feet. When a distance is referred to as so many stations, it means that number of 100-foot lengths. The fractional part of a distance between a full station is called a plus station. Fractions of a foot are indicated by decimals, either to the nearest 0.1 foot or 0.01 foot, depending upon the accuracy of the measurement required. For example, a point on a line 309.2 feet beyond station 10+00 is indicated as station 13+09.2.

Stakes set along the line are marked with waterproof lumber crayon known as "keel", or with ink markers, such as the "Magic Marker". Markings are placed on the face of stakes so that as a person walks along the line in the direction of progressive stationing, the station markings are seen as each stake is approached.

Accurate chaining with a steel tape requires skill on the part of the chainmen in the use of plumb bobs, steel chaining pins, range poles, hand levels, and tension indicator apparatus. This manual is written for execution of the less difficult conservation work. In order to obtain sufficient accuracy, the following should be observed:

1. Keep tape on line being measured.
2. Keep uniform tension on tape for each measurement.
3. "Break" chain on slopes as necessary to keep chain level (Figure 1-20).
4. Accurately mark each station.
5. Keep accurate count of the stations.

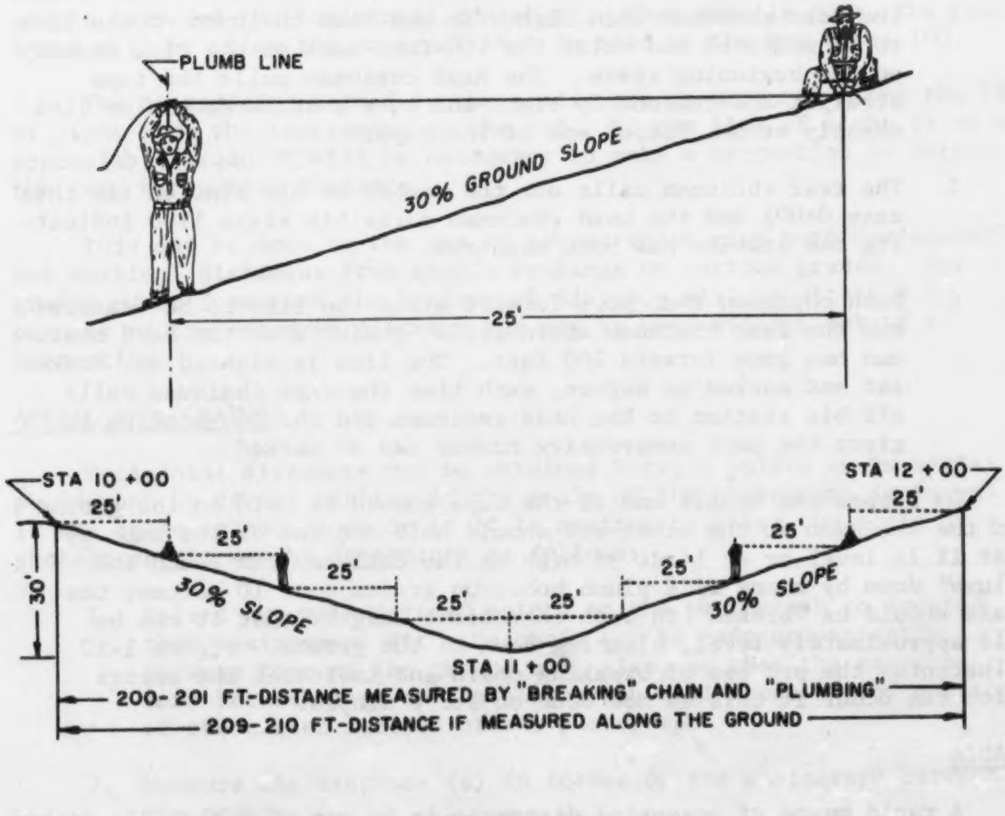

PLUMB LINE
30% GROUND SLOPE
25'
STA 10 +00
STA 12 +00
25'
25'
25'
25'
30'
25'
25'
25'
25'
30% SLOPE
30% SLOPE
STA 11 +00
200-201 FT.-DISTANCE MEASURED BY "BREAKING" CHAIN AND "PLUMBING"
209-210 FT.-DISTANCE IF MEASURED ALONG THE GROUND

Figure 1-20 Breaking chain

The following procedure is generally used for chaining a line within this accuracy:

1. The line to be measured may be a meandering line along a drainage ditch or gully channel or it may be a straight line in a predetermined direction. In the former case the measurements are taken parallel, or nearly so, to the meandering line. In the latter case a range pole is set ahead on the line as far as can be seen, or the direction is marked by a tree, fence post, or other convenient point. This mark is used in sighting in a straight line from the point of beginning.

2. For purposes of this explanation it will be assumed a straight line is to be measured, and a stake has been set at the point of beginning marked 0+00. (See paragraph "Profiles and cross sections" for other methods of stationing the beginning station.)

3. The head chainman takes the zero end of the tape and advances in the general direction of the line to be measured. When he has gone nearly the length of the tape the rear chainman calls out "chain". This signals the head chainman to stop.

4. The rear chainman then sights in the head chainman on the line to be measured and holds the 100-foot mark of the tape exactly on the beginning stake. The head chainman pulls the tape straight and reasonably tight and sets a stake or pin on line exactly at the "zero" end of the tape.

5. The rear chainman calls out the number of his station (in this case 0+00) and the head chainman marks his stake 1+00 indicating one station has been measured.

6. Both chainmen then move forward along the line to be measured and the rear chainman again calls "chain" when the head chainman has gone forward 100 feet. The line is sighted in, stakes set and marked as before, each time the rear chainman calls off his station to the head chainman and the new station is given the next consecutive number and so marked.

On slopes the uphill end of the tape should be held on the ground and the chainman at the other end should hold the end of the tape so that it is level or at least as high as the chainman can reach and "plumb" down by means of a plumb bob. On grades over 10 percent the chain should be "broken" in such convenient lengths that it can be held approximately level, plumbing down to the ground. Figure 1-20 illustrates the process of breaking chain and indicates the errors which can occur if this is not done on steep slopes.

STADIA

A rapid means of measuring distances is by use of the stadia method. It is much faster than chaining and under some conditions is sufficiently accurate.

The equipment required for stadia measurements consists of a telescope with two extra horizontal hairs, called stadia hairs, and a graduated rod (Figure 1-8). Most transits and planetable alidades have stadia hairs and some engineering levels are equipped with them. One of the stadia hairs is above and the other is an equal distance below the horizontal crosshair.

The process of taking a stadia measurement consists of observing through the telescope the interval in feet on the rod between the two stadia hairs when the rod is held vertically on some point. This interval, which is called the stadia interval, is a direct function of the distance from the instrument to the rod. On most instruments the ratio of this distance to the stadia interval may be taken as 100 to 1 with no appreciable error. The exact ratio for instruments with stadia hairs is usually indicated on a card placed in the instrument box. To determine the distance from the instrument to any given point, observe the stadia interval on the rod held on the point and multiply this interval by 100.

In reading stadia intervals it is ordinarily convenient to set the lower stadia hair on some even foot mark and read the interval to the upper stadia hair. When the distance is such that one of the stadia hairs falls off the rod, one-half the interval may be read between one stadia hair and the horizontal crosshair. When this is done, the distance will be twice the interval that is read on the rod times 100.

The distances obtained by the stadia are as measured along the line of sight from the instrument to the rod. If the line of sight is on an appreciable grade it will be necessary to make a correction to obtain the true horizontal distance.

This may be done by the use of tables which give both horizontal and vertical distances from stadia readings on various grades. For grades under 5 percent the horizontal distance will be within 0.3 percent of the measured distance and may be used without making a correction.

AERIAL PHOTOGRAPHS

Horizontal distances may be obtained between points on an aerial photograph by direct scaling if the scale of the photograph is known. If the scale is not known or if it is desired to check the scale of a photograph, it may be determined as follows:

1. Select two well defined points on the photograph so located that measurement with the chain can be made conveniently between them on the ground and, also, so that the measurement between them on the photograph will cross a good portion of the center section of the photograph.

2. Measure the distance (A) in inches on the photograph between the points.

3. Measure the distance (B) in feet on the ground between the points with a chain.

4. Scale of the photograph = $\frac{B}{A}$ feet per inch. The scale thus determined may be applied to other measurements on the same photograph although the measurements near the edge may be affected some by the distortion of the photograph.

9. DIFFERENTIAL LEVELING

GENERAL

Planning and establishment of all mechanical practices used in soil and water conservation work require information regarding the relative elevation of points on the earth's surface.

Three principal methods are used in determining differences in elevation: Barometric, trigonometric, and differential (or spirit) leveling. Differential leveling is the method most commonly used and is the only one explained. It utilizes the phenomenon that a spirit level can be used to fix a line of sight perpendicular to the action of gravity. This line of sight can then be used to determine differences in elevation between nearby points on the earth's surface.

COMMON TERMS USED IN LEVELING

Referring to Figures 1-21 and 1-22 common terms used in leveling are as follows.

Bench Mark (BM)

A bench mark is a point of known elevation of a permanent nature. Such points may be marked with a brass pin or cap set in concrete, a cross or square mark cut on concrete, a long metal stake driven into the ground, a specifically located point on a concrete bridge, culvert, or foundation, or similar objects which are not likely to be disturbed for a long time. Temporary bench marks are points of known or established elevation usually provided for convenient reference in the course of surveys and construction when permanent bench marks are too far distant or inconveniently located. Such bench marks may be established on wooden stakes set near a construction project or on nails driven into trees. Bench marks on trees will have more permanence if set near the ground line where they will remain on the stump if the tree is cut and removed.

U. S. Geological Survey has established bench marks in nearly all major cities in the United States and at scattered points in less populated areas. They are generally bronze caps securely set in stone or concrete with elevations referenced to mean sea level. Their primary purpose is to provide control points for topographic mapping. They are, however, also useful as points from which other bench marks may be established for public or private projects. Other government, state and municipal agencies as well as private and public utility companies have established similar monuments. Such bench marks should be used, when convenient, for the more important surveys.

Turning Point (TP)

A turning point is a point on which the elevation is determined in the process of leveling, but which is no longer needed after necessary readings have been taken. A turning point should be located on a firm object, whose elevation will not change during the process of moving the instrument setup. A small stone, fence post, temporary stake or axe head driven firmly into the ground usually is satisfactory for this purpose.

Backsight (BS)

A backsight is a rod reading taken on a point of known elevation. It is the first reading taken on a bench mark or turning point immediately after the initial or new setup.

Foresight (FS)

A foresight is a rod reading taken on any point on which an elevation is to be determined. Only one backsight is taken during each setup; all other rod readings are foresights.

Height of Instrument (HI)

Height of instrument is the elevation of the line of sight. It is determined by adding the backsight rod reading to the known elevation of the point on which the backsight was taken.

SETTING UP THE LEVEL

Before attempting to set up the level, be sure that the tripod wing nuts have been tightened until each leg when held horizontally will barely fall under its own weight. Next, holding two tripod legs, one in each hand, place the third leg on the ground. Using the third leg as a pivot, move the held legs until the footplate is nearly horizontal. Then without altering the horizontal position of the footplate the two legs can be lowered to the ground. Pressure should then be applied to the legs to insure a firm and stable setup. Be sure that the tripod legs are spread at such an angle that it is stable and that objects may be viewed through the telescope from a convenient posture.

The telescope should then be lined up over one pair of leveling screws and the bubble approximately centered. The process should be repeated with the telescope over the other pair. This procedure is continued until the bubble remains centered or nearly so for any position of the telescope. Final centering of the bubble is usually easier if only one screw is turned rather than trying to adjust two opposite screws at the same time. The leveling screws should be tightened only enough to secure a firm bearing.

Before attempting to take sights the crosshairs should be focused by means of the eyepiece. The telescope should be pointed at some light surface such as a white building or the sky and the eyepiece turned slowly in or out until the most distinct appearance of the crosshairs is obtained. It should then be pointed at, and focused (by means of the focusing screw) on a level rod, held by a rodman, on some point about 100 feet from the instrument. The eye should then be moved slowly up and down to observe if the crosshair apparently moves over the face of the rod. If the crosshair does not appear to move it is properly focused. If movement is detected, further adjustment is necessary. Once the eyepiece has been adjusted no further adjustment is necessary so long as the same individual uses the instrument.

After focusing on the rod the bubble should be exactly centered in the level vial before the rod reading is taken. Be sure the rod is being held vertically or that the reading is taken with the rod in a vertical position. Some surveyors ask the rodman to swing the rod back and forth over center on its base as a pivot. The minimum reading thus observed is the true vertical reading.

Be sure not to lean on the instrument or step close to the tripod legs, since this may throw the instrument off level.

BENCH LEVEL CIRCUIT

The procedure and field notes used in running a bench level circuit may be considered as the basic system for all differential leveling. The beginner should be thoroughly familiar with this basic system. A bench level circuit is run for the purpose of determining the relative elevations of two or more bench marks. The circuit may start from a highway or USGS bench mark or from some point of assumed elevation. A bench level circuit is frequently run as a part of profile or cross section levels or as a part of a topographic survey. The basic procedure and notes will be the same in any event.

On the larger projects it is desirable to run the bench level circuit separately from all the other survey work. If this is not done, and mistakes occur, a great deal of additional work will be required to carry corrections through the survey notes. Bench levels should always be "closed" on the starting point. That is, after the last bench mark is set, levels should be run back to the starting point.

The procedure for running a bench level circuit is as follows:

1. The level is set up at some convenient point between the starting bench mark and the next bench mark or turning point, but usually not over 400 feet from the starting bench mark. It is usually difficult to read the level rod at distances over 500 feet. A little practice will reveal what should be the limiting distance for the particular level being used. It is good practice to keep foresight and backsight distances approximately equal to compensate for any adjustment errors in the instrument.

2. The instrumentman begins his field notes by recording the following information (Figures 1-21 and 1-22).

   a. Location of survey, including name of farm, farmer, or project.

   b. Type of survey such as design survey, construction layout, construction check, or similar description.

   c. Column headings on left-hand sheet.

   d. Names of surveyors.

   e. Date of survey.

   f. Description of starting bench mark. Include reference to the field book in which the elevation of the bench mark was originally recorded. If it is a new bench mark with an assumed elevation, no such notation need be made. However, this assumed elevation should be in even feet, as 100.00 or 200.00 feet.

3. With the rodman holding the rod on the bench mark, the instrumentman observes the rod reading and records it in the backsight column opposite the station (Sta.) BM 1. Referring to Figures 1-21 and 1-22 it will be noted that the backsight on BM 1 was 6.82 feet. This reading added to 144.62 (elevation of BM 1), recorded in beginning the field notes, gives 151.44, the HI, or elevation of the line of sight.

4. The rodman then moves ahead and picks out a convenient point for a turning point, or drives a small stake into the ground for this purpose. The instrumentman turns the telescope and takes a rod reading on this turning point. He records this reading in the foresight (FS) column opposite turning point (TP) 1. In Figures 1-21 and 1-22 the foresight for TP 1 was 5.17 feet. This reading subtracted from the HI, 151.44, gives 146.27, the elevation of the turning point.

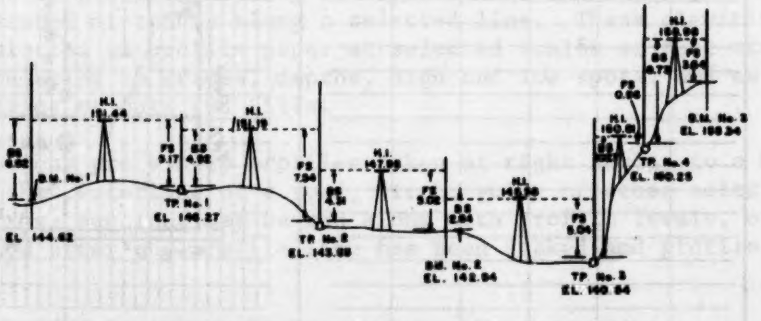
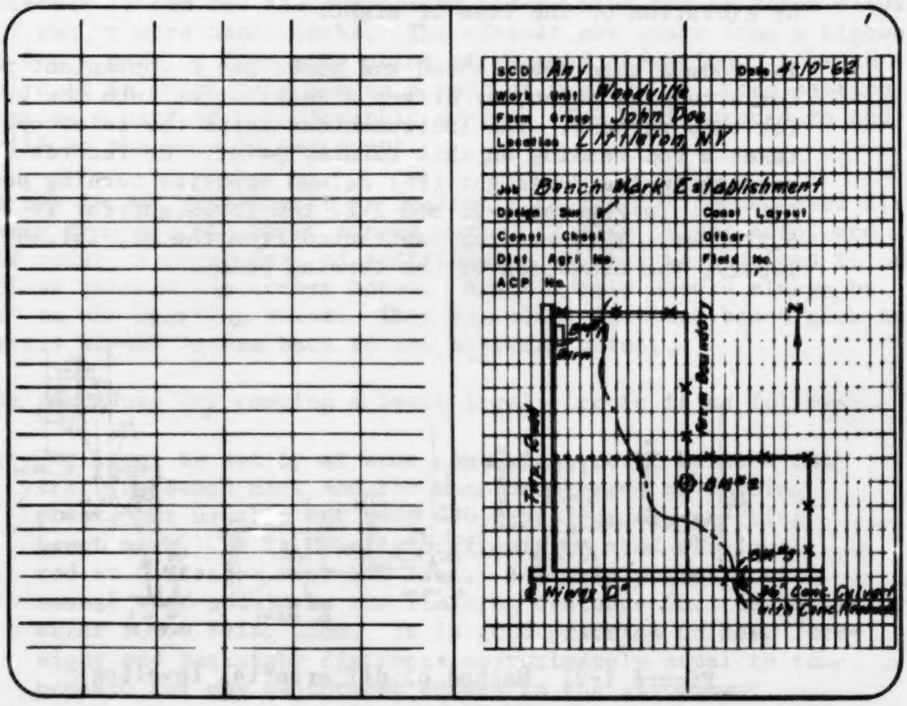


Figure 1-21 Method of differential leveling

5. The instrumentman then picks up the level, moves ahead, and goes through a process similar to that described above, taking a backsight on TP 1, and a foresight on a new turning point ahead.

6. After the elevation of the last bench mark has been determined, the survey party runs levels back to the starting bench mark in order to "close" the circuit. Referring to Figure 1-22, it will be noted that the foresight on BM 3, the last BM in the circuit, was 3.64, giving an elevation of 155.34 for BM 3. In making the return run the instrument is reset and BM 3 used as a turning point so as to be included in the closed circuit. In a bench level circuit bench marks should always be used as turning points.

7. After taking the final foresight on the starting bench mark, the "error of closure" can be determined. This is the difference between the actual elevation of the bench mark and the elevation computed from the final foresight. Referring to Figure 1-22 it will be noted that the elevation computed for the final foresight was 0.02 foot too high or +0.02 foot. Length of circuit is approximately 0.5 mile. To determine permissible error use the formula given under Precision and Accuracy. Substituting we find permissible error = 0.10 $\sqrt{0.5}$ = 0.07. Actual error is 0.02 which is less than that permitted. Level note computations should be checked by adding the backsight and foresight columns as shown in Figure 1-22. The difference should

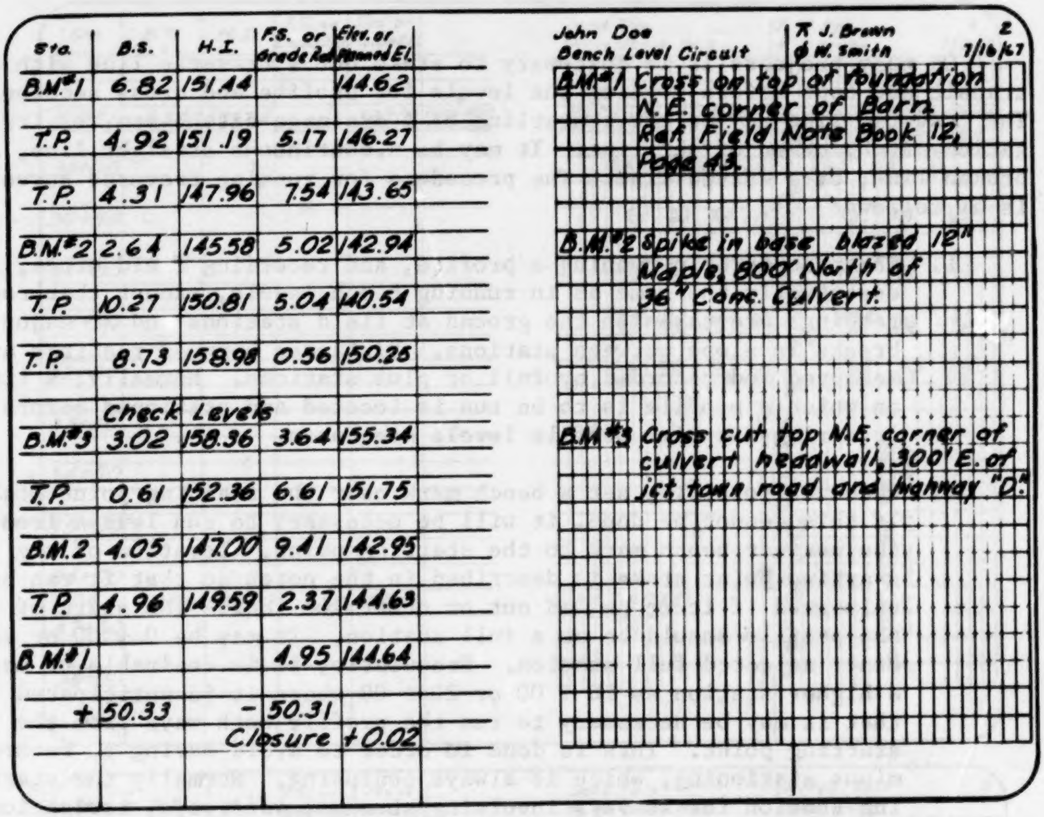


SCD Any Date 4-10-62
Work Unit Woodville
Farm Group John Doe
Location Littleton N.Y.
Job Bench Mark Establishment
Design Sur ✓ Const Layout
Const Check Other
Dist Agr't No. Field No.
ACP No.

1
N
Fence Boundary
BM#2
BM#1
State Hiway 25
36" Conc. Culvert with Conc Headwall

Figure 1-22 Notes - bench level circuit

(sheet 1 of 2)



Sta.	B.S.	H.I.	F.S. or Grade Rod	Elev. or Planned El.
B.M.#1	6.82	151.44		144.62
T.P.	4.92	151.19	5.17	146.27
T.P.	4.31	147.96	7.54	143.65
B.M.#2	2.64	145.58	5.02	142.94
T.P.	10.27	150.81	5.04	140.54
T.P.	8.73	158.98	0.56	150.25
	Check	Levels		
B.M.#3	3.02	158.36	3.64	155.34
T.P.	0.61	152.36	6.61	151.75
B.M.2	4.05	147.00	9.41	142.95
T.P.	4.96	149.59	2.37	144.63
B.M.#1			4.95	144.64
+	50.33	−	50.31	
		Closure		+0.02

John Doe
Bench Level Circuit

⊼ J. Brown
ϕ W. Smith

2
7/16/67

B.M.#1 Cross on top of foundation
N.E. corner of Barn
Ref Field Note Book 12,
Page 43.

B.M.#2 Spike in base blazed 12"
Maple, 800' North of
36" Conc. Culvert.

B.M.#3 Cross cut top N.E. corner of
culvert headwall, 300' E. of
jct town road and highway "D."

Figure 1-22 Notes - bench level circuit
(sheet 2 of 2)

equal the error of closure and should be in the same direction--that is, plus or minus. This check merely proves the accuracy of the addition and subtraction performed in the notes. If the foresights and backsights do not check, it will be necessary to recheck the computation of elevations and heights of instrument until the mistake is found.

PROFILES AND CROSS SECTIONS

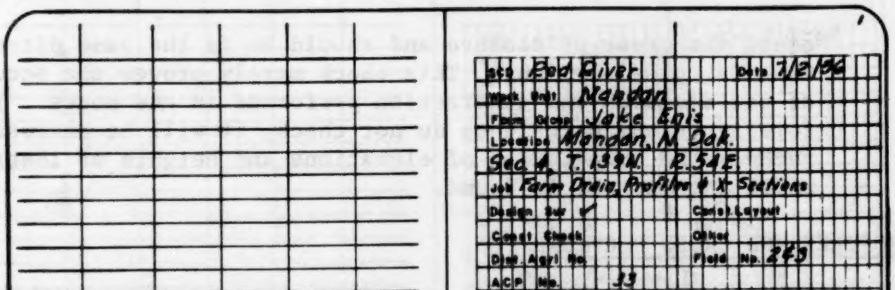
The object of profile leveling is to determine the elevation of the ground at measured distances along a selected line. These elevations can then be plotted on profile paper at selected scales so that studies can be made relating to grades, depths, high and low spots, and estimating of quantities of cuts and fills.

Cross sections are simply profiles taken at right angles to a base line such as the centerline of a road, ditch, gully or other selected base line. Cross sections may be run along with profile levels, or they may be run after the profile line has been staked and profiles taken.

On many projects it is customary to stake out a traverse line with a transit and tape before running the levels for profile and cross sections. The traverse line may be the centerline of a drainage ditch, dam, or irrigation ditch, or an offset line. It may be a continuous straight line, a broken line, or a curved line. The procedure for running traverse surveys is as follows:

1. The procedure in running a profile, and recording field notes, is essentially the same as in running bench levels, except that rod readings are taken on the ground at field stations and at major breaks in slope between stations. Distances between readings are measured and recorded by full or plus stations. Normally, a line on which a profile is to be run is located and stationed before or during the time profile levels are taken.

2. Whenever possible, set a bench mark near the starting point stake. If this cannot be done, it will be necessary to run levels from the nearest bench mark to the starting point. Location of the starting point stake is described in the notes so that it can be relocated if it is pulled out or otherwise lost. The start of the profile should be at a full station. It may be 0 + 00 or any other selected full station. Frequently, it is desirable to use a higher station as 10 + 00 or 20 + 00 where it is anticipated that it may be necessary to run the profile both ways from the starting point. This is done in order to avoid having to record minus stationing, which is always confusing. Normally the starting station for surveys involving streams, waterways, irrigation canals or ditches and gullies should be located at the upstream end and proceed in the direction of flow.

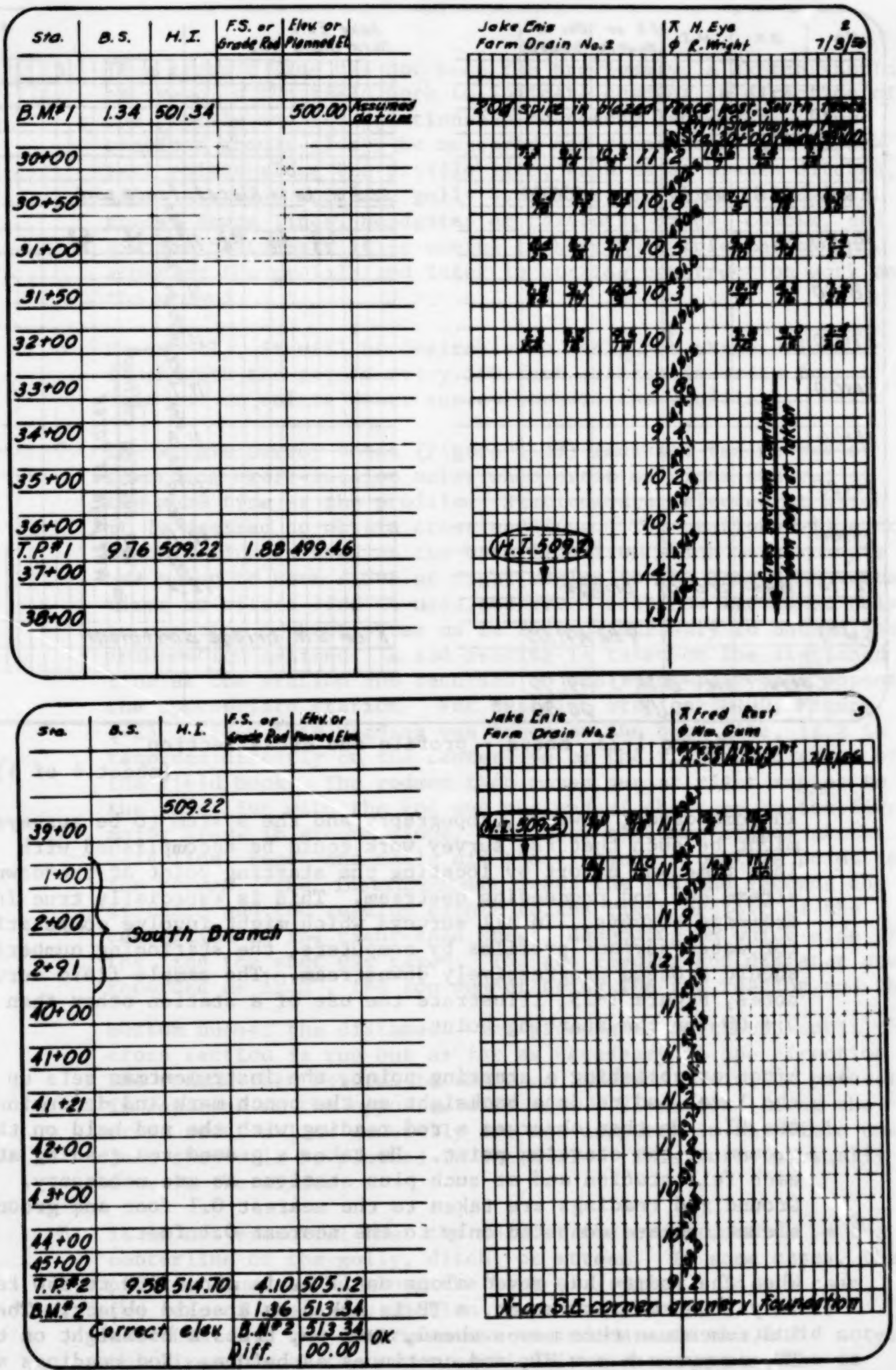


SCD Red River Date 7/2/56
Work Unit Mandan
Farm Operator Jake Enis
Location Mandan, N. Dak.
Sec. 4, T. 139N. R. 54E.
Job Farm Drain, Profiles & X-Sections
Design Sur ✓ Const. Layout
Const. Check Other
Dist. Agri. No. Field No. 243
ACP No. 33

1
32 33
Twp. Road
N
Field 23
B.M. #2
Sta. 45+00
Sta. 22+75
Structure (2)
Sta. 35+00
B.M. #3
Farm Drain
Sta.
Sta. 10+00
B.M. #1
Pasture

B.M. #1 - 20d spike in blazed fence post
B.M. #2 - X on S.E. corner granary foundation
B.M. #3 - X on S.W. Bridge abutment

Figure 1-23 Notes - profile and cross section (sheet 1 of 4)



Jake Enis
Farm Drain No.2
⊼ H. Eye
ϕ R. Wright
2
7/3/58

Sta.	B.S.	H.I.	F.S. or Grade Rod	Elev. or Planned El.	
B.M.#1	1.34	501.34		500.00	Assumed datum
30+00					
30+50					
31+00					
31+50					
32+00					
33+00					
34+00					
35+00					
36+00					
T.P.#1	9.76	509.22	1.88	499.46	
37+00					
38+00					

20d spike in blazed fence post. South [illegible]

H.I. 509.22

Cross sections continued down page as taken

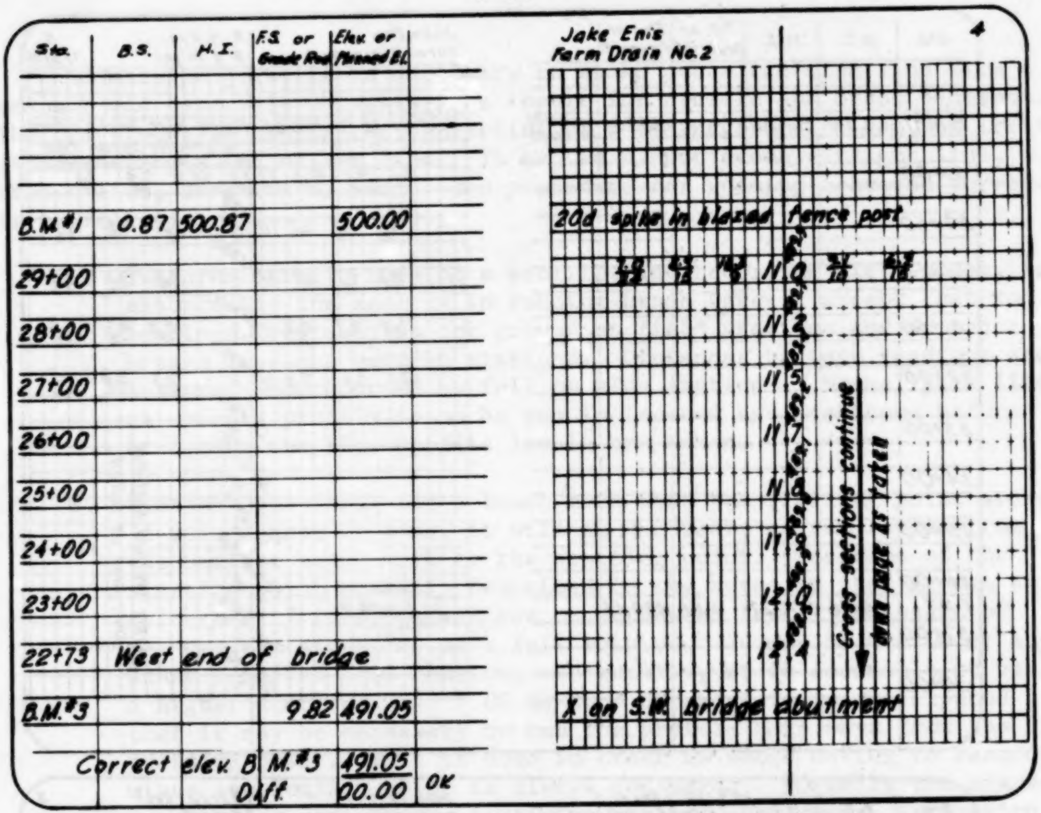
Jake Enis
Farm Drain No.2
⊼ Fred Rest
ϕ Wm. Gums
3

Sta.	B.S.	H.I.	F.S. or Grade Rod	Elev. or Planned Elev.	
		509.22			
39+00					
1+00	South Branch				
2+00					
2+91					
40+00					
41+00					
41+21					
42+00					
43+00					
44+00					
45+00					
T.P.#2	9.58	514.70	4.10	505.12	
B.M.#2			1.36	513.34	
	Correct	elev.	B.M.#2	513.34	OK
			Diff.	00.00	

H.I. 509.22

X on S.E. corner granary foundation

Figure 1-23 Notes - profile and cross section
(sheets 2 and 3 of 4)



Sta.	B.S.	H.I.	F.S. or Grade Rod	Elev. or Planned El.	
B.M.#1	0.87	500.87		500.00	
29+00					
28+00					
27+00					
26+00					
25+00					
24+00					
23+00					
22+73	West end of bridge				
B.M.#3			9.82	491.05	
	Correct elev. B.M.#3			491.05	
			Diff.	00.00	OK

Jake Enis
Farm Drain No. 2
4
20d spike in blazed fence post
11.0
11.2
11.5
11.7
11
11
12.0
12.4
Cross sections continue
down page as taken
X on S.W. bridge abutment

Figure 1-23 Notes - profile and cross section (sheet 4 of 4)

In some cases, however, topography and the system to be surveyed might be such that the survey work could be accomplished with less time and effort by locating the starting point at the downstream end and proceeding upstream. This is especially true for drainage surveys. In all surveys which might involve computations for water surface profiles by computers, the stationing numbering should proceed progressively downstream. The sample field survey notes, Figure 1-23, illustrate the use of a station other than 0 + 00 for the starting point.

3. After establishing a starting point, the instrumentman sets up the level and reads a backsight on the bench mark and determines the HI. He then observes a rod reading with the rod held on the ground at the starting point. He takes a ground rod reading at each full station and at such plus stations as are necessary. Ground rod readings are taken to the nearest 0.1 foot and ground elevations are computed only to the nearest 0.1 foot.

4. When the rodman has moved along until he is about 300 to 350 feet away from the instrument, a TP is taken on a solid object. The instrumentman then moves ahead, sets up, takes a backsight on the TP, computes a new HI, and continues as before. Rod readings and elevations on TP's and BM's should be read and recorded to 0.01 foot.

5. If a transit line has not been run previously, a sketch should be drawn in the field book to indicate changes in direction of the profile and its relationship to nearby landmarks. Plus stations should always be measured and recorded at all important points along the profile line, such as at branch ditches, tile laterals, gullies, gully overfalls, culverts, bridges, roads, fence lines, headgates or takeouts, drops, checks, and similar features. It is useful to have this information in studying the profile and later in staking construction work on the ground.

6. Frequently, it will be desirable to set a hub stake driven flush with the ground every 500 feet or less in order to "tie in" or relate other survey work to the profile.

7. The sample survey notes (Figure 1-23) indicate the method of recording cross-section notes when cross sections are run at the same time as the profile. Stations are selected at which it is desired to obtain cross sections. The stationed line or transit line is used as the base line from which measurements are taken to both sides at right angles to the base line. Sometimes an offset line is used and cross sections are taken only to one side or both sides as is deemed necessary to obtain the information desired. A rod reading is taken on the stationed line at the station and recorded on the right-hand page opposite the appropriate station. For example, station 30+00, Figure 1-23. Since this reading was taken on the base line, 11.2 is recorded directly on the centerline of the right-hand sheet of the field book. The rodman then moves out at right angles to the base line with the rod and one end of the tape to the first major break in ground slope. The rear chainman stands at the base line, reads and calls off the distance from this point to the rodman. The instrumentman reads the rod and records the distance and rod reading either to the right or left of the centerline of the right-hand sheet, depending on which side of the line the shot was taken. The rod reading and distance are recorded as $\frac{10.6}{7}$, the top number being the rod reading and the bottom number the distance. The process is continued until the cross section is run out as far as necessary in one direction. The rodman then returns to the base line and a similar process is repeated in the opposite direction. Elevations along the cross section line generally are not computed in the field unless they will be plotted in the field. This work is usually done in the office.

8. It is not essential that the zero of the cross section be the centerline of the gully, ditch, or stream. In some cases, the profile line may be along the bank of a ditch. In any case, the zero of the cross section is on the base line. It is essential for the instrumentman to indicate in the field notes the direction of the cross section in such a manner that it

will be clear. It is standard practice to refer to "right" and "left" when facing in the direction of progressive stationing of the profile line. Where a cross section is taken at a proposed structure site it should be located so that this line may be reproduced later if required. This can be done by setting a hub stake at the zero point of the cross section and one or more additional stakes on the cross-section line 30 to 100 feet from the zero point. These stakes should be driven nearly flush with the ground so they will not be disturbed and guard stakes driven beside them for protection and ease in finding.

9. Cross sections are generally taken to compute volume or quantities of material. Sometimes they are taken to study the hydraulic characteristics of gullies, streams, or other meandering watercourses. They do not provide a very satisfactory method of constructing a topographic sketch. For methods of topographic mapping, see Control and Topographic Surveys.

USE OF GRADE ROD

In surveys for construction layout and construction checking, it is often more convenient and timesaving to use grade rod readings determined from the established height of instrument since it eliminates the need for converting rod readings to elevations at each layout or checkpoint.

Grade rod is the reading that would be obtained from the present instrument position if the rod were placed at the planned grade. (Grade rod = HI - planned grade elevation.) When the height of instrument is above grade elevation the grade rod has a plus value and is so marked in the notes, such as +6.3. If the height of instrument is below grade elevation, the grade rod has a minus value and is so marked as -8.3.

To find the cut or fill in construction layout surveys, the actual ground rod reading is subtracted algebraically from the grade rod. If the result has a minus value, a fill is indicated. If the result has a plus value, a cut is indicated. For example: If the HI is 249.3 and the planned grade elevation is 243.0, the grade rod would equal 249.3 minus 243.0 or 6.3. If the foresight of the point were 9.8 then 6.3 minus 9.8 would equal -3.5, indicating a fill. If the foresight were 5.1, then 6.3 - 5.1 would equal +1.2, indicating a cut. See Figure 1-24.

Figure 1-25 illustrates survey notes for design, construction layout and construction check of a small field ditch project. A few prior random shots with a level indicated the ditch could be constructed to provide the necessary surface drainage on a .0005 bottom grade with a 1-foot drop at its outlet to the bottom of the main ditch.

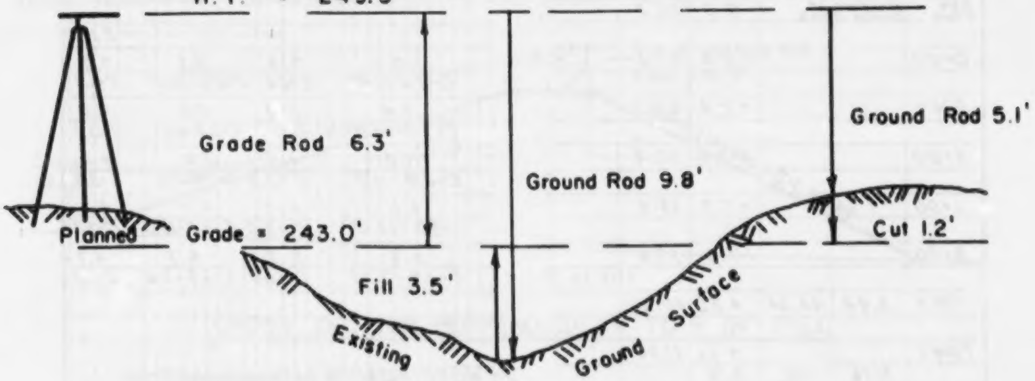
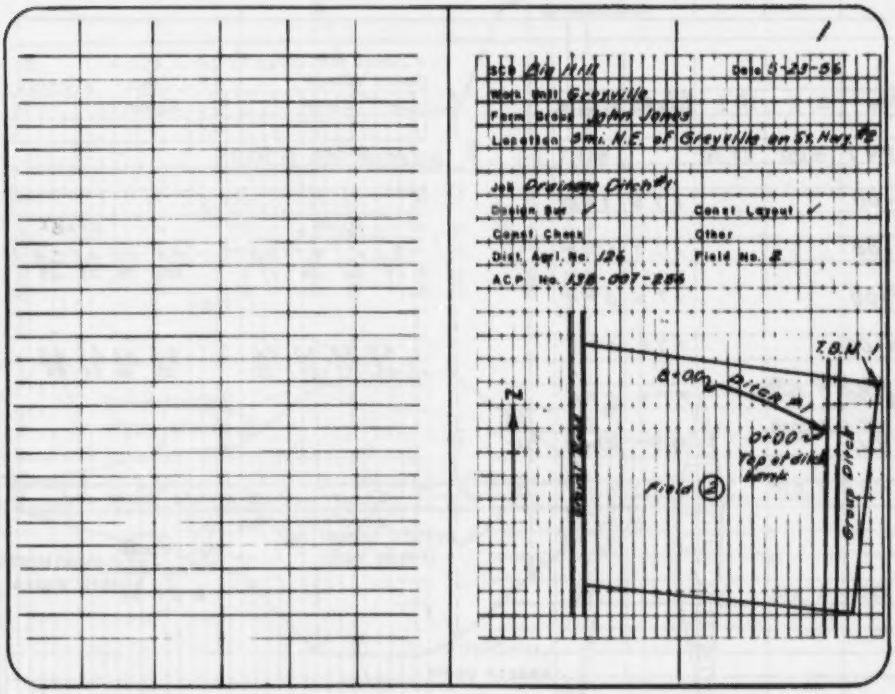

H. I. = 249.3'
Grade Rod 6.3'
Ground Rod 9.8'
Ground Rod 5.1'
Planned Grade = 243.0'
Fill 3.5'
Cut 1.2'
Existing Ground Surface

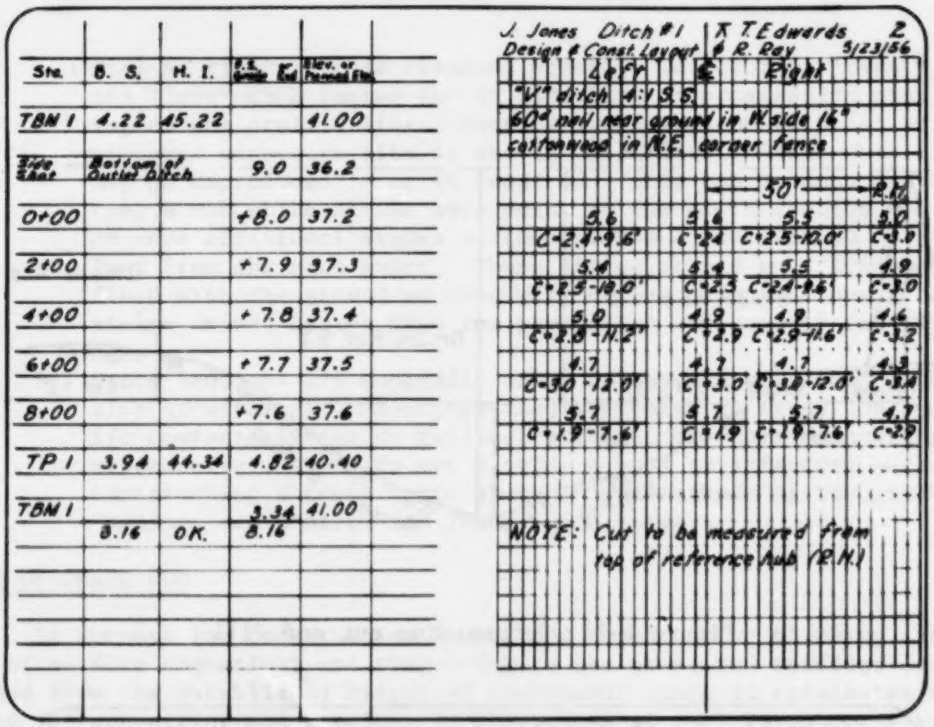
Figure 1-24 Determining cut and fill


1

SCS Big Hill Date 5-25-56
Work Unit Greyville
Farm Group John Jones
Location 3 mi. N.E. of Greyville on St. Hwy. #2
Job Drainage Ditch #1
Design Svy ✓ Const Layout ✓
Const Check Other
Dist. Agri. No. 126 Field No. 2
A.C.P. No. 138-007-256

T.B.M. 1
6+00
Ditch #1
0+00
Top of ditch bank
Field ②
Group Ditch
N

Figure 1-25 Notes - ditch survey using grade rod
(sheet 1 of 3)



Sta.	B. S.	H. I.	F.S. or Grade Rod	Elev. or Planned Elev.	
TBM 1	4.22	45.22		41.00	
Side Shot	Bottom of Outlet Ditch		9.0	36.2	
0+00			+8.0	37.2	
2+00			+7.9	37.3	
4+00			+7.8	37.4	
6+00			+7.7	37.5	
8+00			+7.6	37.6	
TP 1	3.94	44.34	4.82	40.40	
TBM 1			3.34	41.00	
	8.16	OK.	8.16		

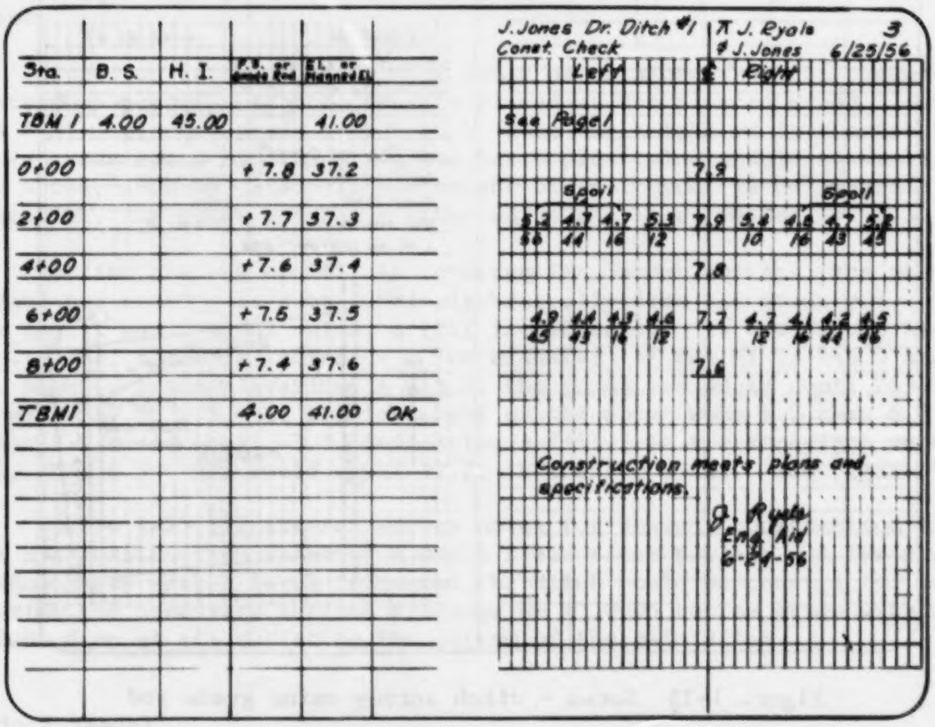
J. Jones Ditch #1
Design & Const. Layout
⊼ T. Edwards
ϕ R. Ray
2
5/23/56

"V" ditch 4:1 S.S.
60d nail near ground in W side 16" cottonwood in N.E. corner fence

← 50' → R.H.

Left	℄	Right	
5.6 C-2.4-9.6'	5.6 C+2.4	5.5 C+2.5-10.0'	5.0 C-3.0
5.4 C+2.5-10.0'	5.4 C+2.3	5.5 C-2.4-9.6'	4.9 C-3.0
5.0 C+2.8-11.2'	4.9 C+2.9	4.9 C+2.9-11.6'	4.6 C-3.2
4.7 C-3.0-12.0'	4.7 C+3.0	4.7 C+3.0-12.0'	4.3 C-3.4
5.7 C+1.9-7.6'	5.7 C+1.9	5.7 C+1.9-7.6'	4.7 C-2.9

NOTE: Cut to be measured from top of reference hub (R.H.)



Sta.	B. S.	H. I.	F.S. or Grade Rod	El. or Planned El.	
TBM 1	4.00	45.00		41.00	
0+00			+7.8	37.2	
2+00			+7.7	37.3	
4+00			+7.6	37.4	
6+00			+7.5	37.5	
8+00			+7.4	37.6	
TBM1			4.00	41.00	OK

J. Jones Dr. Ditch #1
Const. Check
⊼ J. Ryals
ϕ J. Jones
3
6/25/56

Left ℄ Right

See Page 1

Spoil				℄			Spoil	
				7.9				
5.2 56	4.7 44	4.7 16	5.3 12	7.9	5.4 10	4.6 16	4.7 43	5.2 45
				7.8				
4.9 45	4.4 43	4.3 16	4.6 12	7.7	4.7 12	4.1 16	4.2 44	4.5 46
				7.6				

Construction meets plans and specifications.

J. Ryals
Eng. Aid
6-24-56

Figure 1-25 Notes - ditch survey using grade rod
(sheets 2 and 3 of 3)

SETTING SLOPE STAKES

Slope stake setting is part of layout procedure widely used to guide and check earthwork construction. The following is an example of setting slope stakes for an earth dam using the grade rod method.

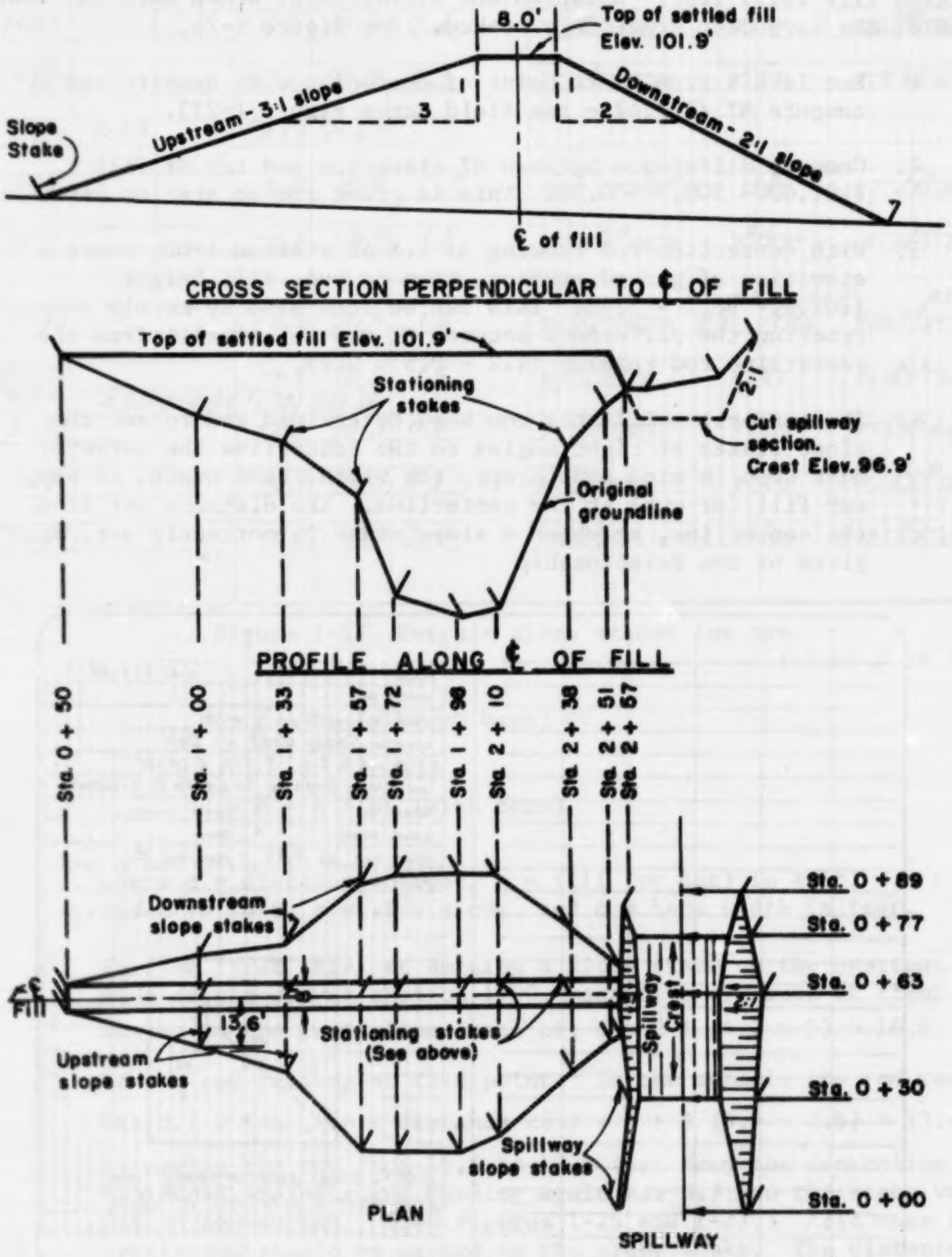

8.0'
Top of settled fill
Elev. 101.9'
Upstream - 3:1 slope
Downstream - 2:1 slope
3
1
2
1
Slope Stake
℄ of fill
CROSS SECTION PERPENDICULAR TO ℄ OF FILL
Top of settled fill Elev. 101.9'
Stationing stakes
2:1
Cut spillway section.
Crest Elev. 96.9'
Original groundline
PROFILE ALONG ℄ OF FILL
Sta. 0 + 50
Sta. 1 + 00
Sta. 1 + 33
Sta. 1 + 57
Sta. 1 + 72
Sta. 1 + 98
Sta. 2 + 10
Sta. 2 + 38
Sta. 2 + 51
Sta. 2 + 57
Sta. 0 + 89
Sta. 0 + 77
Sta. 0 + 63
Sta. 0 + 30
Sta. 0 + 00
Downstream slope stakes
℄ Fill
13.6'
Stationing stakes (See above)
Upstream slope stakes
Spillway
Crest
Spillway slope stakes
PLAN
SPILLWAY

Figure 1-26. Location of slope stakes

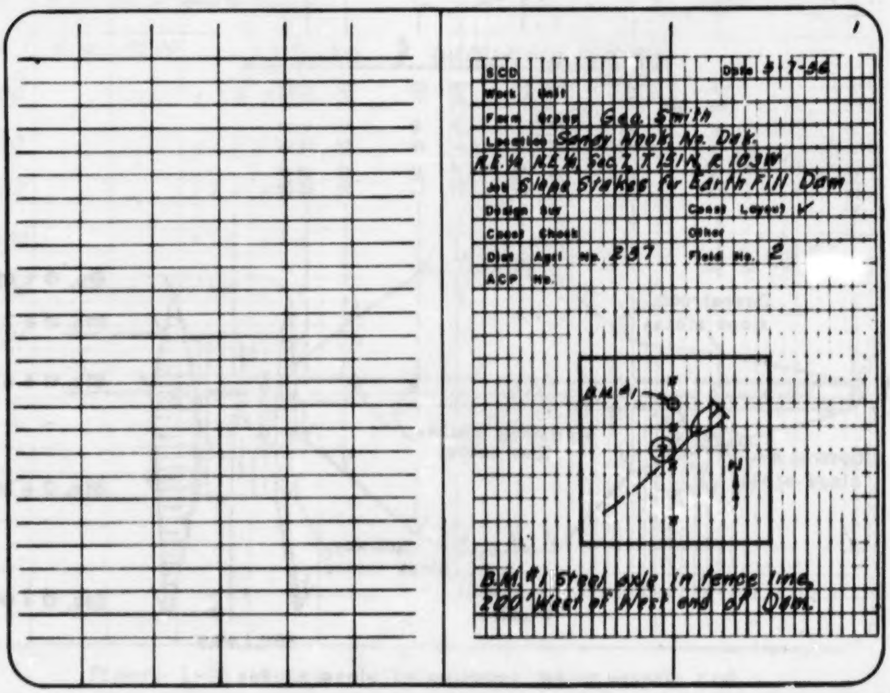
The procedure given can be applied to excavation of ditches, diversions, spillways and other embankment work as levees and dikes requiring construction to specified slopes. In the example, assume that the earthfill will be staked to the following dimensions: Top width 8 feet, upstream side slope 3:1, downstream side slope 2:1, elevation to top of settled fill 101.9 feet. Location and elevation of bench mark and centerline of dam have been previously staked. See Figure 1-26.

1. Run levels from BM to point of convenience at damsite and compute HI (102.42 - see field notes Figure 1-27).

2. Compute difference between HI elevation and top of fill (102.42 - 101.9 = 0.5). This is grade rod at station 1+00.

3. With centerline rod reading of 4.2 at station 1+00, compute elevation of ground surface, then compute fill height (101.9 - 98.2 = 3.7). This can be done also by merely subtracting the difference between HI and top of fill from the centerline rod reading (4.2 - 0.5 = 3.7).

4. The centerline fill has now been determined and to set the slope stakes at right angles to the centerline the surveyor must keep in mind side slope, top width, berm width, if any, and fill (or cut) at the centerline. The distance out from the centerline, at which a slope stake is correctly set, is given by the relationship



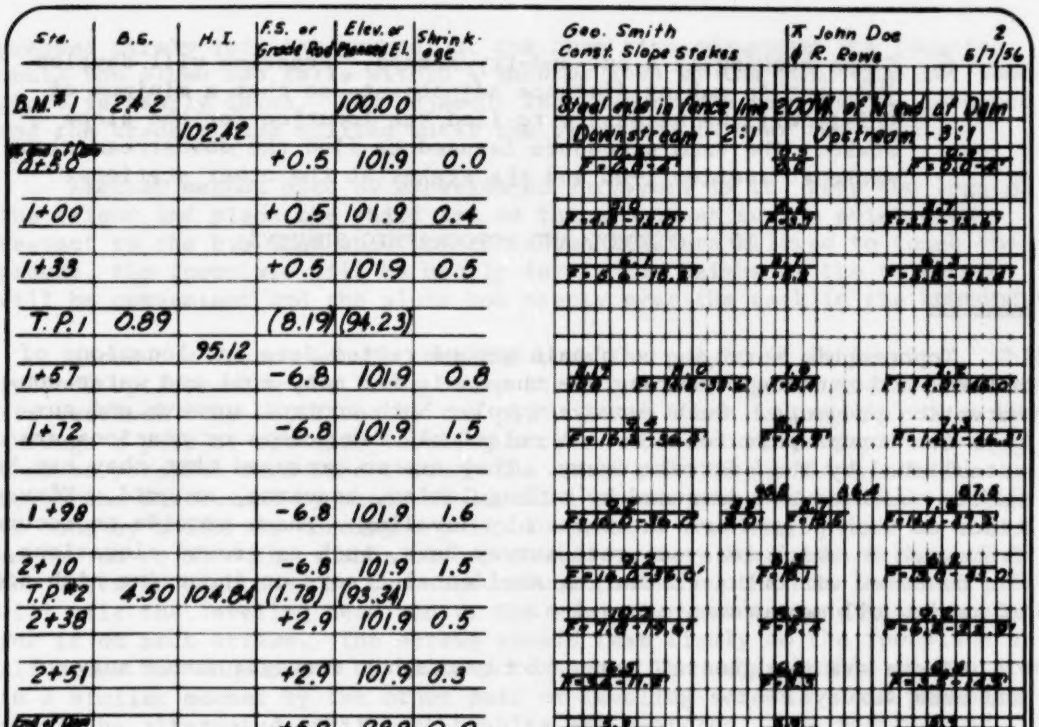
1

SCD Date 9-7-56
Work Unit
Farm Group Geo. Smith
Location Sandy Hook, No. Dak.
NE 1/4 NE 1/4 Sec 2, T 151N, R 103W
Job Slope Stakes for Earth Fill Dam
Design Sur Const Layout ✓
Const Check Other
Dist Agrl No. 257 Field No. 2
ACP No.

BM #1 Steel axle in fence line, 200' West of West end of Dam.

Figure 1-27 Notes - slope stakes for dam

(sheet 1 of 2)



Sta.	B.S.	H.I.	F.S. or Grade Rod	Elev. or Planned El.	Shrinkage
B.M.#1	2.42			100.00	
		102.42			
[illegible] 0+50			+0.5	101.9	0.0
1+00			+0.5	101.9	0.4
1+33			+0.5	101.9	0.5
T.P.1	0.89		(8.19)	(94.23)	
		95.12			
1+57			-6.8	101.9	0.8
1+72			-6.8	101.9	1.5
1+98			-6.8	101.9	1.6
2+10			-6.8	101.9	1.5
T.P.#2	4.50	104.84	(1.78)	(93.34)	
2+38			+2.9	101.9	0.5
2+51			+2.9	101.9	0.3
[illegible] 2+57			+5.9	98.9	0.0

Geo. Smith
Const. Slope Stakes
⊼ John Doe
ϕ R. Rowe
2
6/7/56

Steel axle in fence line 300' W of N end of Dam
Downstream - 2:1
Upstream - 3:1

Figure 1-27 Notes - slope stakes for dam
(sheet 2 of 2)

$$d = \frac{w}{2} + hs \text{ (without berm) or}$$

$$d = \frac{w}{2} + b + hs \text{ (with berm)}$$

where d = distance in feet, h = fill (or cut) in feet, w = top width in feet, s = side slope, and b = berm width in feet.

5. For the first trial at setting a slope stake on the upstream side of the dam at station 1+00, measure a distance at right angles to the centerline stake of, $d = \frac{8}{2} + (4.2 \times 3) = 16.6$.

   Take a rod reading at this point. In the example the rod reading was 3.7 which gave a distance of $d = \frac{8}{2} + 3\ (3.7 - 0.5) = 13.6$. By moving the rod from 16.6 to 13.6 feet from the centerline it was found that the rod reading again was 3.7; so the stake was put in and marked. (See Figures 1-26 and 1-27.) Allowance for settlement should be marked on the slope stake. The distance, rod reading and elevation are recorded in the field book.

6. Slope staking is a cut-and-try method. Practice will develop judgment in making distance adjustments so that a minimum of trials will be necessary to find the location for the slope stake. The same procedure is used to find the downstream slope stake at station 1+00 and the stakes at the other stations.

10. CONTROL AND TOPOGRAPHIC SURVEYS

GENERAL

Topographic surveys, to obtain ground relief data and locations of natural and manmade features, are the basis for many soil and water conservation projects. Such surveys involve both control surveys and surveys for topographic features. A relatively few points or stations are established by the control survey. They are so arranged that they can be easily observed and measured by triangulation, traverse, or grid. Elevations of such points are determined by leveling. These provide an accurate framework on which less accurate survey data, such as ground elevations, can be based without accumulating accidental errors or incurring high cost of making all measurements precise.

There are two general types of topographic surveys; route surveys and area surveys.

Route surveys are comprised of ribbon-or strip-shaped tracts as would be required of a natural stream and a drainage or irrigation ditch. Route surveys are open traverses whose horizontal control throughout their length is fixed by stationing (as described under Chaining, Measurement of Horizontal Distances) and by offset ties. Such traverses may not be checked completely by calculations. However, when started and ended on points of known position, the surveys become closed traverses of the connecting type for which complete mathematical checks can be made. Vertical controls can be determined in conjunction with the traverse survey or independently from a closed circuit of differential levels.

Area surveys are comprised of block-shaped tracts as for a pond or reservoir site, a surface drainage plan, or irrigation system. An area survey requires a closed traverse with a control network of stations and bench marks, even though it is only a rudimentary one for a small tract.

Several types of surveys are used in making route and area surveys. These are covered in the following parts of this chapter.

SETTING UP THE TRANSIT

The transit is the primary instrument for making route or area surveys. Ordinarily the transit is set over some definite point, such as a tack in a hub. The plumb bob provides a means of centering the instrument over the point. The transit can be placed approximately over the point and the tripod legs adjusted until the tripod head is nearly level. The instrument can then be picked up bodily, without disturbing the position of the legs, and carefully set over the point. Each leg should then be pressed firmly into the ground, at the same time adjusting its location until the plumb bob falls within ½ inch or less of the point and the footplate is nearly level. Two adjacent leveling screws can then be loosened and the transit head shifted until the plumb bob is over the point.

Another method used by experienced surveyors is to grasp two legs of the tripod and place the third leg on the ground at such a point with respect to the hub that when the other two legs are allowed to touch the ground, the footplate will be nearly level, the height of the telescope will be convenient and the plumb bob nearly over the tack in the hub.

After the instrument is centered over the point, it is leveled. This is done by loosening the lower clamp screw and turning the instrument about its vertical axis until one of the plate level tubes is parallel to a line through a pair of opposite leveling screws. The second plate bubble will then be parallel to a line through the other pair of leveling screws. Level the instrument by means of leveling screws and plate bubbles. This is done by uniformly turning a pair of opposite leveling screws in such a manner as to move the thumbs either toward or away from each other. Thus one screw is tightened by the same amount that the other is loosened. This will tilt the leveling head and at the same time maintain definite support for it on both screws. The screws should rest firmly on the footplate at all times but should not be allowed to bind. The other bubble is centered in a similar manner by the other pair of leveling screws. This process should be alternated until both bubbles are centered. The position of the plumb bob should now be observed. If it has moved off the point, it should be reset by shifting the head and releveling the instrument as just described.

The instrument is now ready for the measurement of horizontal and vertical angles. Transits have two verniers for reading horizontal angles, the zeros being 180° apart. The horizontal circles of transits are graduated in various ways. They may be graduated to 30 minutes reading to one minute, graduated to 20 minutes reading to 30 seconds, graduated to 15 minutes reading to 20 seconds, or graduated to 20 minutes reading to 20 seconds. The graduations on the circle usually are numbered at intervals of 10° continuously from 0° to 360° in both directions from 0°. The inner row of numbers increases in a clockwise direction, while the outer row increases in a counterclockwise direction. The verniers are provided so that the angle can be read closer than the smallest circle division. In every case the graduations on the vernier depend upon the subdivision of the circle. For example, when the circle is graduated in half degree (30') spaces, the space between each line on the vernier will be 29/30 of the 30' arc space on the circle; thus an arc consisting of 29 divisions of 30' each (equivalent of 14°30' on the circle) is subdivided into 30 equal parts to obtain the space between the lines on the vernier. One division on the vernier then is 01' less in angular measurement than one division of the circle. When the horizontal angles are measured with the transit, the inner circle within the vernier moves with the telescope while the outer circle remains fixed. The zero of the vernier always points to the reading on the outer circle.

Measuring Horizontal Angles

When a horizontal angle is to be measured both the upper and lower clamps are loosened and the zero of the vernier is set close to 0 on the circle. The upper clamp is then tightened and by means of the upper slow motion screw, the index of the vernier is set exactly opposite 0 on the circle. The telescope is now directed at one of the objects to be sighted and when the object is in the field of view and near the vertical hair, the lower clamp is tightened. The vertical hair is set exactly on the object by means of the lower slow motion screw. The telescope should be focused carefully.

The upper clamp is now loosened and the telescope is sighted on the second object. The upper clamp is tightened, and the slow motion screw is used to bring the object on the vertical crosshair. The angle can now be read by adding to the circle reading the minutes read on the vernier. To eliminate instrument errors, the angle can be measured again with the telescope inverted and the mean of the measured angles taken. Another procedure is to measure the angle by repetition, once with the telescope direct and once reversed and the mean taken as the measurement of the angle. The vernier is read in the direction the angle is turned.

Measuring Vertical Angles

To measure a vertical angle, the instrument is carefully leveled and the telescope is directed to the object. When the object is observed in the telescope, the vertical motion is clamped and by means of the vertical motion tangent screw the middle horizontal crosshair is set exactly on the point. The reading on the vertical arc is the vertical angle. When the point is above the horizontal plane, the angle is called a positive angle or angle of elevation; when the point is below the horizontal plane, the angle is called a negative angle or angle of depression. In the survey notes, they are designated by a + sign and a - sign, respectively.

If the instrument line of sight and the axis of the telescope bubble are not in adjustment, it is impossible to obtain a correct vertical angle with the vertical arc only. If the instrument has a full vertical circle, the error can be eliminated by reading the vertical angle first with the telescope direct and then reversed and taking the average of the two readings.

In Figure 1-28, a 01' vernier is shown with its zero opposite the zero (360) of the circle, ready to measure an angle. The vernier lines on both sides of zero fail to match the lines on the circle by 01'; the next lines of the vernier fail to match the lines of the circle by 02', and so on. Setting exactly at zero can best be accomplished by noting that the first vernier lines on either side of zero fail to match the circle divisions by the same amount.

Figure 1-29 shows a one-minute vernier reading 17°25' from left to right and 342°35' from right to left.

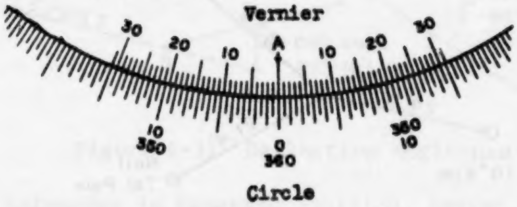


Figure 1-28 One minute vernier set at 0°

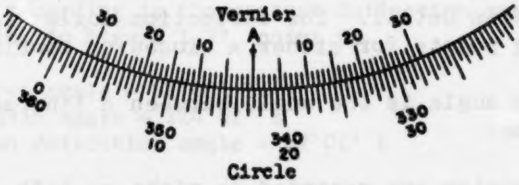


Figure 1-29 One minute vernier set for measurement

TRANSIT TRAVERSE BY DEFLECTION ANGLES

This type of survey applies primarily to the control traverse of the route or area survey where good accuracy is required. Establishing distance between traverse points may be done by stadia or chaining. The use of the chain is recommended when a high degree of accuracy is required. The transit is used to keep chainmen on line and to obtain any vertical angles necessary to correct inclined distances to true horizontal.

Angles are measured with the transit. Checks are made by doubling the angles or repeating the angular measurement a sufficient number of times to obtain the desired precision. Angles are measured in several ways: 1) By turning to the right; 2) measurement of the interior angles; 3) measurement of the deflection angles; or 4) measurement of the azimuths.

Important points or stations should be "tied in" so that they may be readily found or replaced. Not less than three horizontal measurements to the nearest 0.10 foot should be taken from readily identifiable permanent points to the station. The measurements should be carefully recorded by means of a sketch in the notes as in Figure 1-30.

In an area survey the transit station may have many points to which measurements are taken to obtain adequate information for construction of a map. Sometimes the collection of details is taken as the work of laying out the transit line proceeds; for others the details are obtained after

the transit line has been established and checked. If the survey covers a large territory, the latter procedure is most likely to be used.

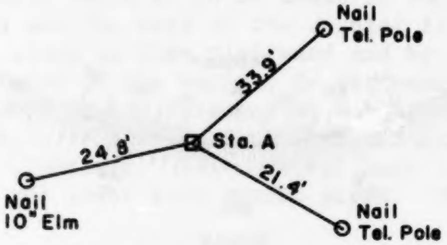


Figure 1-30 Ties to traverse station

The procedure used to run a transit traverse is much the same for one type of traverse as for another. Since most traverse surveys used in Soil Conservation work consist of establishing a route and since the deflection-angle traverse is the one most commonly used for this purpose, it will be explained in detail. The deflection angle traverse provides a means of locating points for either a closed or continuous traverse.

A deflection angle is the angle between a line and the extension of the preceding line.

Deflection angles are recorded as right or left. In Figure 1-31 the angle at B is 29°- 10' left because the angle was measured counterclockwise from the prolongation of the preceding line (A-B). The angle at C is 48°30' right because the angle was measured clockwise from the extension of line B-C.

This method of angular measurement readily lends itself to the calculation of bearings if one of the lines is known.

In Figure 1-31, the bearing of line A-B is given as S 82°E., therefore:

bearing of line B-C = 180°- 82°- (29°10') = N 68°50' E.
bearing of line C-D = 180°- (68°50') - (48°30') = S 62°40' E.

The following procedures are used in taking deflection angles:

1. Set transit on point E and set index of vernier at 0°. (See Figure 1-32.)

2. With lower clamp loose, sight on point D and tighten clamp. With lower slow motion screw, sight point D exactly. (Telescope is direct.)

3. Reverse telescope, loosen upper clamp and rotate transit about its vertical axis in the direction (to the left) of point F. Tighten upper clamp and by means of tangent screw sight point F exactly. The angle is then read and recorded. (62°00' L)

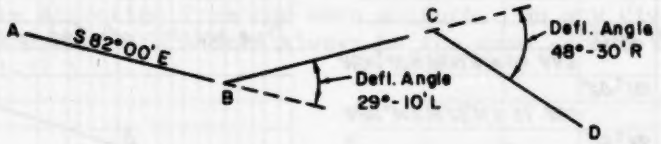


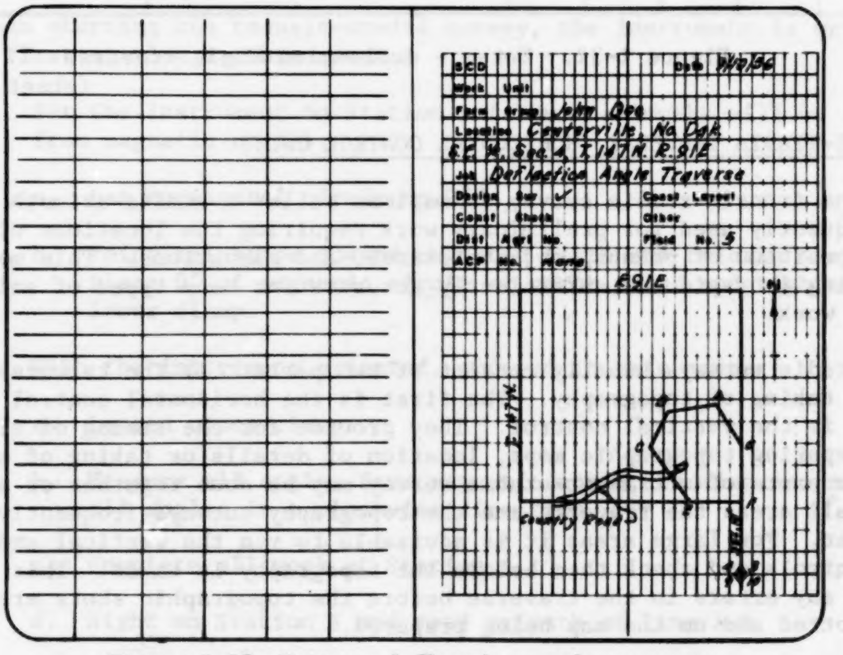
Figure 1-31 Deflection angles

4. Leaving telescope in reversed position, loosen lower clamp and rotate transit about vertical axis and sight point D again by use of tangent screw and lower clamp.

5. Rotate telescope (now in direct position) and turn angle (to the left) and sight point F by means of upper clamp and tangent screw. The angle has been doubled (124°02' L) and one-half of the total recording is the correct deflection angle to use. For example, in Figure 1-32, point E,

   First angle = 62°00' L
   Double angle = 124°02' L
   Mean deflection angle = 62°01' L

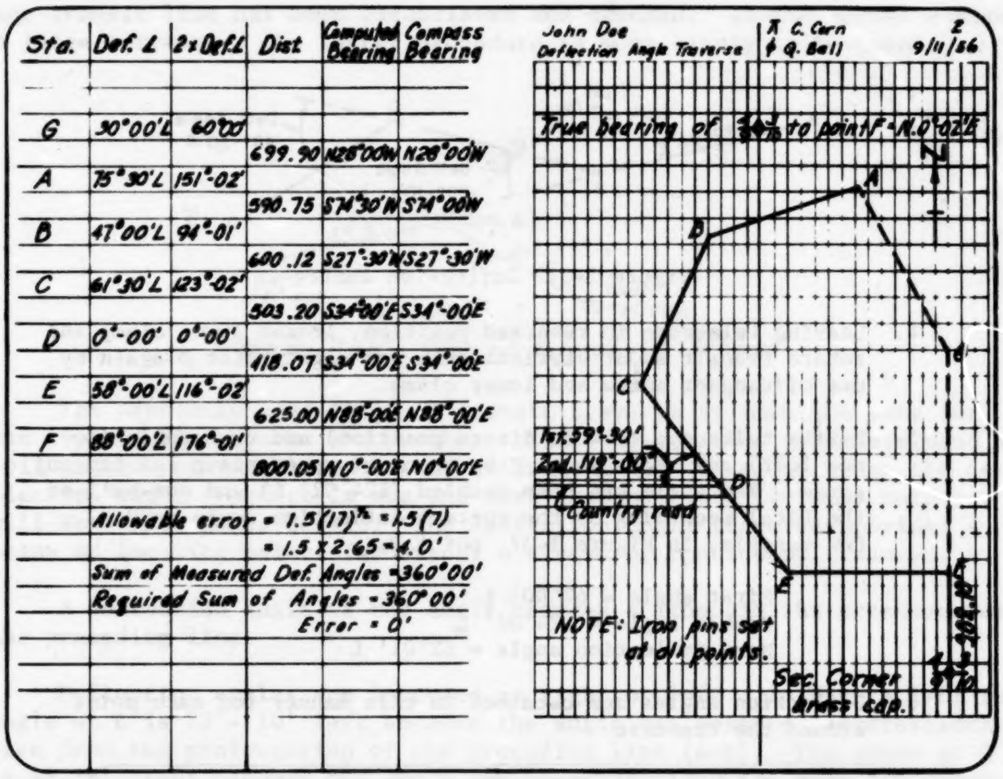
6. Deflection angles are obtained in this manner for each point around the traverse.



SCD Date 9/4/56
Work Unit
Farm Grp John Doe
Location Centerville, No. Dak.
S.E. ¼ Sec. 4, T.147N. R.91E
Job Deflection Angle Traverse
Design Sur ✓ Const. Layout
Const. Check Other
Dist. Agrt. No. Field No. 5
ACP No. None

R91E
N
T.147N.
Country Road

Figure 1-32 Notes - deflection angle traverse
(sheet 1 of 2)



Sta.	Def. ∠	2 x Def. ∠	Dist	Computed Bearing	Compass Bearing
G	30°00'L	60°00'			
			699.90	N28°00'W	N28°00'W
A	75°30'L	151°-02'			
			590.75	S74°30'W	S74°00'W
B	47°00'L	94°-01'			
			600.12	S27°-30'W	S27°-30'W
C	61°30'L	123°-02'			
			503.20	S34°00'E	S34°-00'E
D	0°-00'	0°-00'			
			418.07	S34°-00'E	S34°-00'E
E	58°-00'L	116°-02'			
			625.00	N88°-00'E	N88°-00'E
F	88°00'L	176°-01'			
			800.05	N0°-00'E	N0°-00'E

Allowable error = 1.5(17)$^{1/2}$ = 1.5(7)
= 1.5 x 2.65 = 4.0'
Sum of Measured Def. Angles = 360°00'
Required Sum of Angles = 360°00'
Error = 0'

John Doe
Deflection Angle Traverse
⊼ C. Corn
ϕ Q. Ball
2
9/11/56

True bearing of [illegible] to point F = N.0°02'E
N
A
B
C
G
1st. 59°-30'
2nd. N9°-00'
D
Country road
E
F
NOTE: Iron pins set at all points.
Sec. Corner
Brass cap.

Figure 1-32. Notes - deflection angle traverse
(sheet 2 of 2)

TRANSIT-STADIA TRAVERSE (HORIZONTAL CONTROL ONLY)

The transit-stadia survey (sometimes called a stadia-azimuth survey) is frequently used for preliminary work requiring the locations of boundaries, position of points, objects, lines, and elevations. This method of surveying is rapid and sufficiently accurate for many types of soil conservation work.

Stadia surveys usually consist of two parts: 1) The traverse, and 2) the taking of topography. The first is the horizontal control and the second is the vertical control. They provide for the taking of elevations for preparing topographic maps, location of details or taking of side shots. The two parts of a transit-stadia survey may be done together or separately. For small areas the traverse and the topography surveys frequently are done together. For large areas it is advisable to run the vertical and horizontal controls and check them before the topography is taken. This will detect any errors in the traverse before the topographic shots are taken and plotted and on the map being prepared.

The fieldwork consists of determining horizontal angles (azimuths) to points or objects and obtaining distances between points by stadia. When running a traverse by the transit-stadia method, all directions and angles are referred to a reference line. This line may be an established line from a previous survey, a true meridian, magnetic meridian, or an assumed meridian. The measurement of the azimuth angle is always made in a clockwise direction from the zero azimuth. On any given survey the position of zero azimuth should always be the same -- usually north. (See Figure 1-33.)

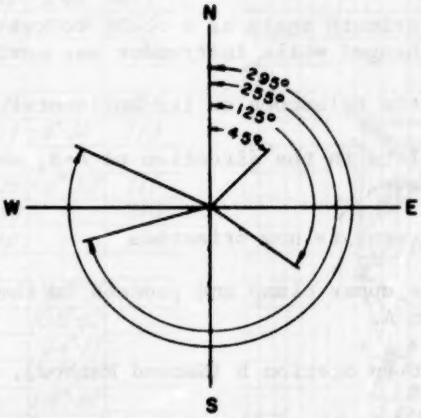


Figure 1-33 Azimuths from north

When starting the transit-stadia survey, the instrument is oriented at the first station in this manner:

1. Set the instrument on Station A (assume azimuths will be taken from magnetic north).

    a. Set horizontal circle on 0°.

    b. Point telescope toward magnetic north and release needle. Place 0° of magnetic circle at north point and tighten lower clamp.

2. With the instrument oriented, proceed in this manner:

    a. Loosen upper clamp.

    b. Measure all angles from magnetic north, turning and reading all angles in a clockwise direction.

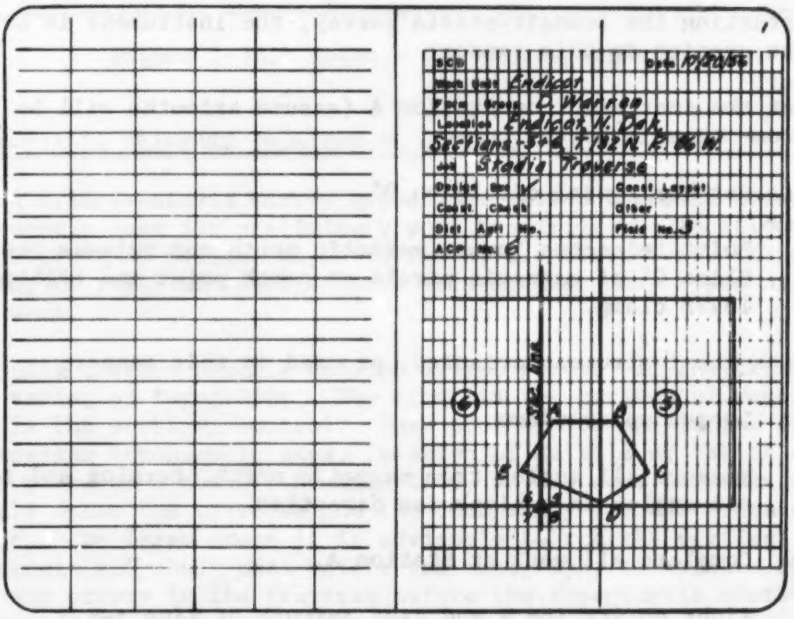
    c. Complete all work at Station A.

    d. Sight on Station B and read azimuth of line A-B.

    e. Keep this azimuth reading set on the circle and move instrument to Station B.

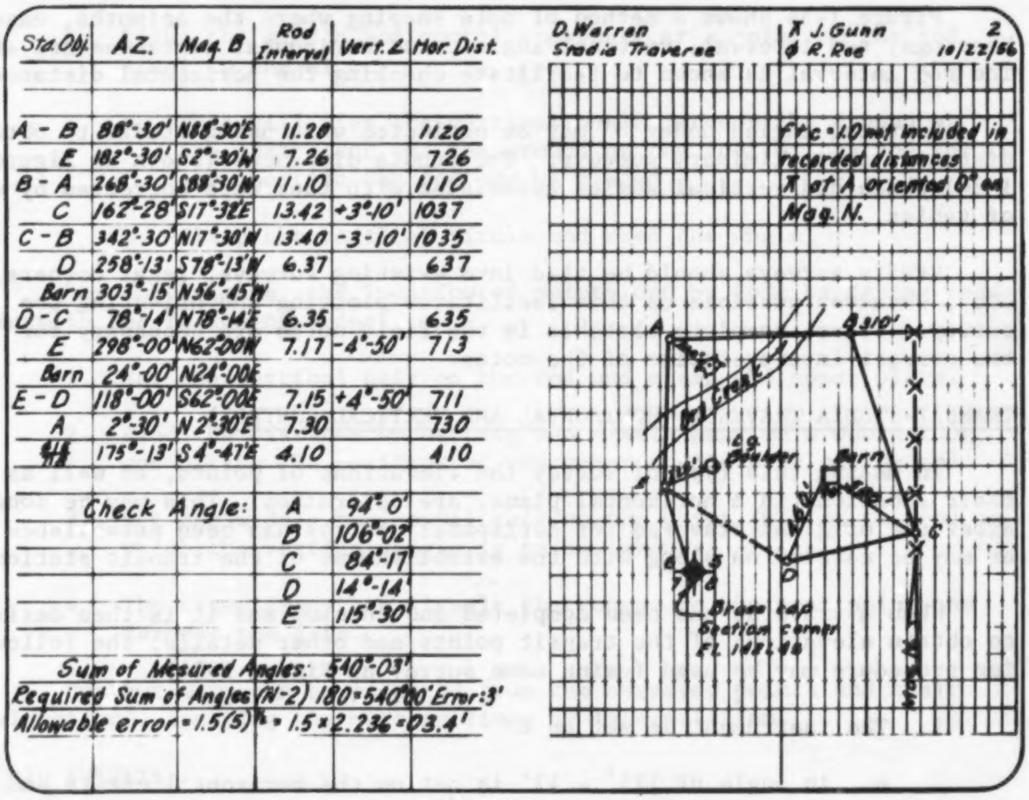
In order to carry the direction of the meridian from one transit station to the next (Station A to B) one of two methods may be used.

1. Set instrument on Station B (First Method).
   - a. Invert the telescope and sight on A.
   - b. Tighten lower clamp.
   - c. Read the azimuth again as a check to see that the reading was not changed while instrument was moved from A to B.
   - d. Now turn the telescope on its horizontal axis (plunged).
   - e. It now points in the direction of A-B, whose azimuth we already have.
   - f. The instrument is now oriented.
   - g. Loosen the upper clamp and proceed in the same manner as at Station A.
2. Set instrument on Station B (Second Method).
   - a. Determine azimuth of line B to A by subtracting 180° from the azimuth reading of line A-B if the azimuth is greater than 180°, or adding 180° to the azimuth reading of line A-B if the azimuth is less 180°.



SCD
Date
Endicott
C. Warren
Location Endicott N. Dak.
Sections 3+4, T.132 N. R. 56 W.
Stadia Traverse
Const. Layout
Const. Check
Other
Field No. 3
ACP No. 6
4
3
A
B
C
D
E
6
7
5

Figure 1-34 Notes - stadia traverse survey for horizontal control (sheet 1 of 2)



D.Warren
Stadia Traverse

⊼ J.Gunn
ϕ R.Roe

2
10/22/56

Sta.Obj.	AZ.	Mag. B	Rod Interval	Vert. ∠	Hor. Dist.
A - B	88°-30'	N88°30'E	11.28		1120
E	182°-30'	S2°-30'W	7.26		726
B - A	268°-30'	S88°30'W	11.10		1110
C	162°-28'	S17°-32'E	13.42	+3°-10'	1037
C - B	342°-30'	N17°-30'W	13.40	-3-10'	1035
D	258°-13'	S78°-13'W	6.37		637
Barn	303°-15'	N56°-45'W			
D - C	78°-14'	N78°-14'E	6.35		635
E	298°-00'	N62°00'W	7.17	-4°-50'	713
Barn	24°-00'	N24°-00'E			
E - D	118°-00'	S62°-00'E	7.15	+4°-50'	711
A	2°-30'	N2°30'E	7.30		730
[illegible]	175°-13'	S4°-47'E	4.10		410
Check Angle:			A	94°-0'	
			B	106°-02'	
			C	84°-17'	
			D	14°-14'	
			E	115°-30'	

Sum of Mesured Angles: 540°-03'
Required Sum of Angles (N-2) 180 = 540°00' Error: 3'
Allowable error = $1.5(5)^{1/2} = 1.5 \times 2.236 = 03.4'$

F+c = 1.0 not included in recorded distances
⊼ at A oriented 0° on Mag. N.

Figure 1-34 Notes - stadia traverse survey for horizontal control (sheet 2 of 2)

b. Set the circle on the azimuth reading of line B-A, but sight to A with telescope direct and with instrument now oriented at B, proceed with survey as before.

This latter method avoids the danger of the circle setting becoming shifted as the instrument is carried from Station A to B. It also eliminates any error resulting from the line of sight not being perpendicular to the horizontal axis. (In Method 2, the telescope is not plunged.) There is a possibility, however, of computing the back azimuth BA incorrectly.

Distances between transit stations are read twice; that is, a reading is taken from A to B and from B to A (See Figure 1-34). At each setup of the instrument a distance reading will be made both backward and forward. This will give two independent stadia readings between transit stations and the average of the two readings will be the most probable value and also serve as a check.

Whenever possible, stadia readings should be taken with the telescope approximately level, thereby eliminating the necessity for reading vertical angles.

Figure 1-34 shows a method of note keeping where the azimuths, magnetic bearings, rod interval, vertical angles, and horizontal distances are shown. The rod interval is shown to facilitate checking the horizontal distances.

Vertical angles under 2° may be neglected when using stadia to obtain distances on preliminary surveys. The stadia distances (shown in Figure 1-34) which had vertical angles associated with them were corrected by use of tables.

Stadia surveys should be tied into existing surveys, legal corners, etc., whenever possible as this facilitates plotting and orienting the survey. Clear, complete sketches in the field notes are necessary for the correct interpretation of the notes.

TRANSIT-STADIA TRAVERSE (HORIZONTAL AND VERTICAL CONTROL)

In making this type of survey the elevations of points, as well as their locations in a horizontal plane, are determined. This may be done after the original traverse for horizontal control has been established or may be carried on along with the establishment of the transit stations.

When a traverse has been completed and checked and it is then desired to obtain elevations of the transit points and other details, the following procedure may be used (using same survey as Figure 1-34).

1. The instrument is set on E.
   a. An angle of 175° - 13' is set on the horizontal circle and instrument is sighted on $\frac{6/5}{7/8}$. This is the azimuth of E to $\frac{6/5}{7/8}$ (See Figure 1-34).

   b. Instrument is now oriented.

   c. Proceed with establishing elevations as follows:

   Find elevation of point E and HI by taking rod reading (4.63) on bench mark $\frac{6/5}{7/8}$ (elevation 1421.45). Next, measure instrument height with tape (4.37). Then, 1421.45 + 4.63 - 4.37 = elevation of point E = 1421.71. (A bench mark with an assumed elevation may be used if sea level datum is not required.) Last, turn azimuths, take stadia readings and elevations of points accessible to Point A.

When it is necessary to take vertical angles for the determination of elevations, proceed as follows:

1. Tie a narrow band of red cloth around rod to mark HI (4.37').

2. Sight the middle horizontal crosshair at a point on the rod equal to the HI.

   a. This will give the vertical angle between the ground at the instrument and the ground at the foot of the rod for any location the rod may be placed.

   b. Clamp the vertical circle and read the angle.

For convenience, the location of points can be done by taking readings in the following order:

1. Set the vertical hair on the rod and clamp the upper plate.

2. Read the distance by setting one stadia hair on a whole foot, and noting the position of the other stadia hair on the rod.

3. Set the middle horizontal hair on the point (HI) on the rod to which the vertical angle is to be taken.

4. The transitman then signals the rodman to the next point and records the data.

Contour maps can be prepared from the surveyed points and their elevations, locating the contour lines by interpolation.

GRID SURVEYS

Grid surveys are particularly applicable to surveys of small areas and where substantial topographic data are needed. The system is simple in that a level, rod and tape are all that are necessary, but it may require more time than planetable and alidade or transit and stadia surveys.

Obtaining topography by use of the grid system consists of selecting and laying out a series of lines on the ground that can be reproduced to scale on paper. All topography, including ground elevation, is then obtained in the field with reference to these lines and later plotted. Contour lines can be drawn in by interpolating between plotted ground elevations.

In any survey for a topographic sketch, a survey plan must be determined in advance. The following factors should be considered:

1. What ground features are conveniently located for use as base lines?

2. Can the base lines be reproduced on a drawing in their true relationship to each other?

3. How far apart shall gridlines be set?

4. How close together will ground elevations need to be taken?

5. What is the most efficient procedure to use?

In planning the survey procedure, it should be remembered that rod readings for elevations cannot be read with accuracy over approximately 300 feet with the ordinary level and level rod. If a stadia rod is used, it can be read at a distance of 500 to 600 feet. Ordinarily there should not be over approximately 200 feet between any two adjacent shots for ground elevations. On very flat uniform terrain this distance might be increased to 300 feet. These factors will help to determine how far apart ground elevations should be taken.

In some instances it will be necessary to establish right angles for making grid layouts. If the surveying instrument does not have a horizontal circle for turning off right angles, they can be established by the 3-4-5 method. See Figure 1-35. An alternate procedure is to use a right angle prism. The prism saves time and is sufficiently accurate for grid layouts and taking cross sections.

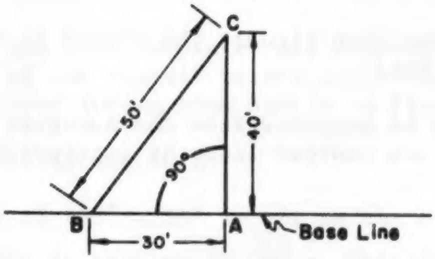


Figure 1-35 "3-4-5" method of laying out a right angle

The following example gives the procedure for gridding a field. See Figure 1-36 with accompanying field notes in Figure 1-37. It is assumed that a level with a horizontal vernier is available for use in laying out right angles from base lines and gridlines. This gridding procedure has the advantage over other systems in that a smaller number of instrument setups is required for taking the levels. Also the entire job can be done with a two-man survey party at a reasonable rate.

In the example, a particular area is to be gridded for preparation of a topographic map. Inspection of this area on an aerial photo showed that the north line of the area was the farm boundary, was well defined, clear of brush, and would serve best as the base line. Further inspection showed that the south field boundary was parallel to the north boundary and that the east and west sides diverged from the north to the south.

1. First an on-site check was made to determine if this gridding plan was workable. No trees, hills, or other obstacles were noted that would prevent use of the plan. A sketch of the field and grid plan, Figure 1-36, was made in the field notebook. A range pole was set in the northwest corner of field

at point A,2. This point was called A,2 so that no minus coordinates would have to be used. Had it been called A,0 or A,1 the point at the southwest corner of the field might be G, (0-1) or some other minus designation. Distances of 400 feet and 600 feet from A,2 were chained off eastward along the base line and a range pole set at A,6 and a stake set at A,8.

2. The level was then set up over stake A,8 sighted on range pole at A,2 and a 90 degree angle turned off. Then a range pole was sighted in and set at point G,8. This established direction for gridline 8. Line 8 was then chained off, beginning at point A,8 and working toward the range pole at point G,8. Long stakes were set at 200-foot intervals along the line. Rear chainman lined-in each stake by eye between succeeding stake and range pole at G,8. The distance between points F,8 and G,8 was found to be 190 feet, and so noted on field book sketch.

3. Gridlines D and E were staked next. The level was set up over points D,8 and E,8 respectively and 90 degree angles turned off from line 8. Long stakes were set at 200-foot intervals on each line, starting measurement from the level and staking to east field boundary, then returning and staking to west field boundary.

4. Line 6 was then staked, starting at point G,6 on the south property line, chaining off 190 feet to correspond to the stake previously set at F,8. Staking of line 6 was continued at 200-foot intervals to the range pole at A,6. This completed lines 6 and 8.

5. With the four grid lines staked, the elevation shots for the entire field can be completed without further use of tape and with a minimum of pacing measurements, simply by locating any other points by lining in by eye from the N and S and E and W stakes. Obviously, the grid line stakes must be distinguishable for several hundred feet. A field up to 60 acres in area can be gridded with a four-line layout such as this. A three-man party can lay out and stake these lines in much less time than it takes two men. A motor vehicle can be used to advantage in setting range poles and distributing stakes when crops and other field conditions will permit. Survey notes, Figure 1-37, illustrate a commonly used method of keeping notes for this type of survey. Note the intermediate shots that are not on regular grid points. Most all gridding will require some intermediate shots to locate and get elevations in low spots, high spots, existing ditches, etc. A sheet of cross-section paper on a clipboard or on a planetable is often used to record the survey notes directly on a sketch drawn to scale in the field.

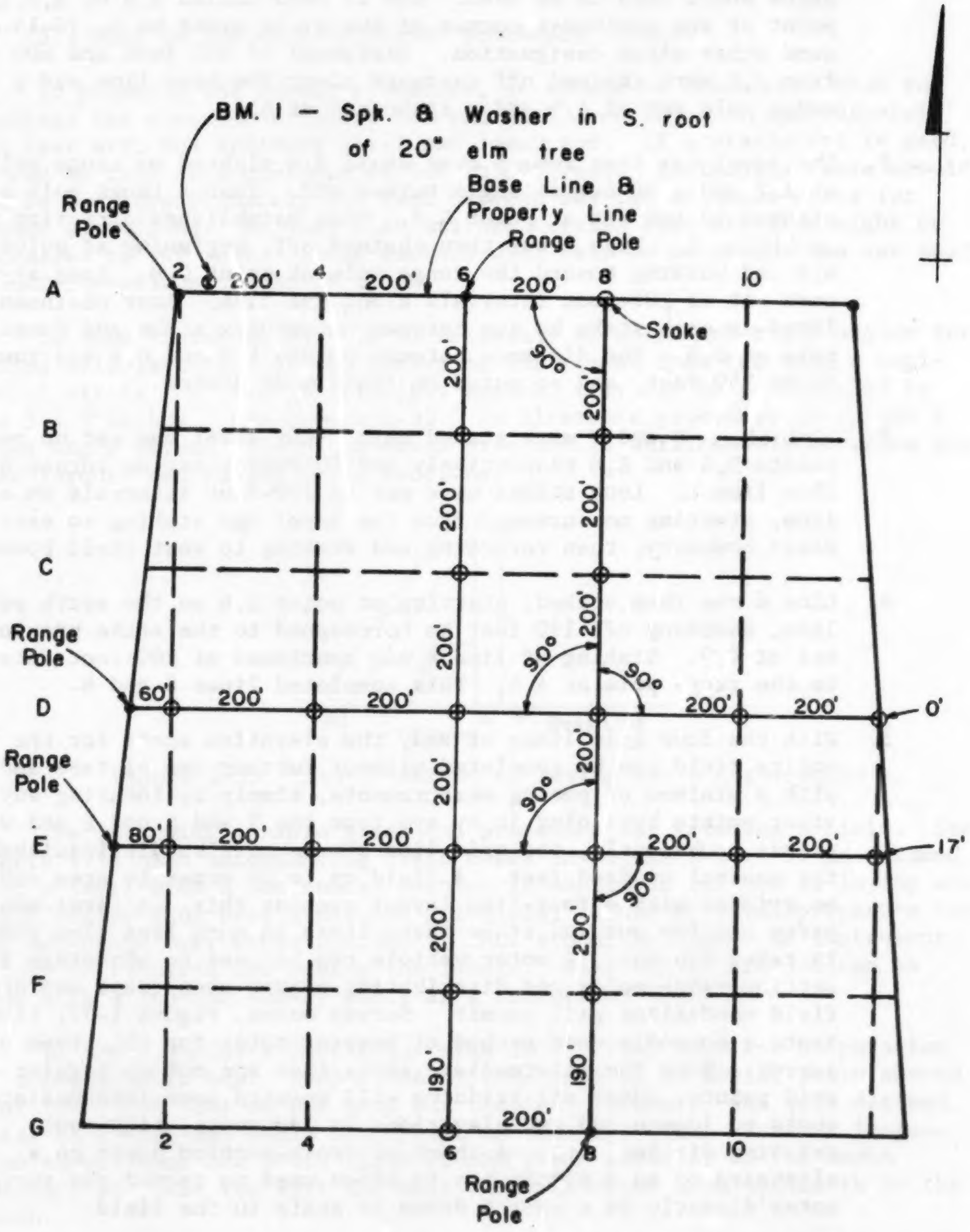
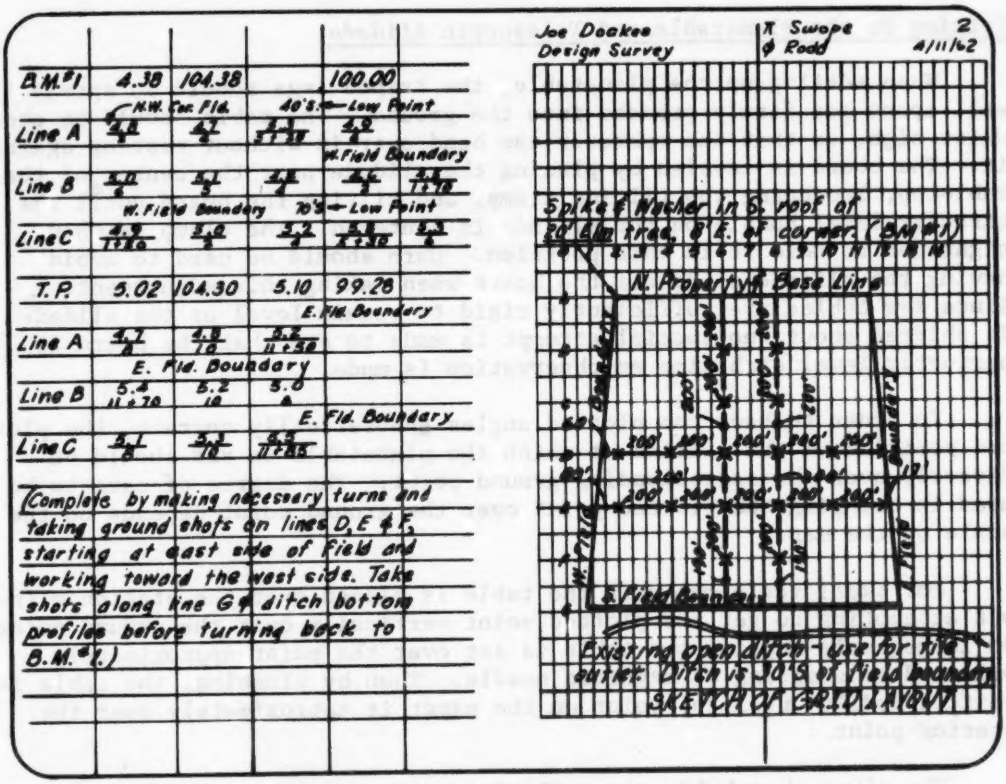

BM. I — Spk. & Washer in S. root of 20" elm tree
Range Pole
Base Line & Property Line
Range Pole
Stake
Range Pole
Range Pole
Range Pole
A
B
C
D
E
F
G
2
4
6
8
10
200'
90°
60'
80'
190'
0'
17'

Figure 1-36 Method of topographic survey by gridding



B.M.#1	4.38	104.38		100.00	
	N.W. Cor. Fld.		40'S. ← Low Point		
Line A	$\frac{4.8}{3}$	$\frac{4.7}{4}$	$\frac{5.1}{5+38}$	$\frac{4.9}{6}$	
				W. Field Boundary	
Line B	$\frac{5.0}{6}$	$\frac{5.1}{5}$	$\frac{4.8}{4}$	$\frac{4.6}{3}$	$\frac{4.6}{1+10}$
	W. Field Boundary		70'S ← Low Point		
Line C	$\frac{4.9}{1+10}$	$\frac{5.0}{3}$	$\frac{5.2}{4}$	$\frac{5.1}{5+30}$	$\frac{5.3}{6}$
T.P.	5.02	104.30	5.10	99.28	
			E. Fld. Boundary		
Line A	$\frac{4.7}{8}$	$\frac{4.8}{10}$	$\frac{5.2}{11+50}$		
	E. Fld. Boundary				
Line B	$\frac{5.4}{11+70}$	$\frac{5.2}{10}$	$\frac{5.0}{8}$		
			E. Fld. Boundary		
Line C	$\frac{5.1}{8}$	$\frac{5.1}{10}$	$\frac{5.5}{11+85}$		

(Complete by making necessary turns and taking ground shots on lines D, E & F, starting at east side of field and working toward the west side. Take shots along line G & ditch bottom profiles before turning back to B.M.#1.)

Joe Doakes
Design Survey

⊼ Swope
ϕ Rodd

2
4/11/62

Spike & Washer in S. root of 20" Elm tree, 8' E. of corner. (BM #1)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
N. Property & Base Line
200'
200'
200'
200'
200'
200'
200'
200'
200'
200'
200'
171'
W. Field Boundary
E. Field Boundary
S. Field Boundary
Existing open ditch - use for tile outlet. Ditch is 30' S. of field boundary
SKETCH OF GRID LAYOUT

Figure 1-37 Notes - grid survey

TOPOGRAPHIC SURVEYS WITH PLANETABLE AND ALIDADE

General

A topographic map may be made directly by the use of a planetable and an alidade. Elevations may be obtained with a level or they can be obtained with an alidade if it has a telescope with level bubble attached. A planetable is nothing more than a drawing board which can be mounted on a tripod and has an arrangement for leveling and for rotating about a vertical axis. The table size most commonly used is 24 inches by 31 inches. Screws are provided for attaching drawing paper to the board.

The alidade is an instrument containing a line of sight and a straightedge parallel to it. The line of sight may be a peepsight provided by standards at either end of the straightedge or it may be a telescope mounted on a standard and fixed with its line of sight parallel to the straightedge. The telescope is provided with a spirit level (ordinarily a detachable striding level) so the line of sight may be made horizontal. The telescopic alidade is the more useful of the two instruments. Mapping with it on a planetable is one of the fastest means available for obtaining topographic information.

Setting Up the Planetable and Telescopic Alidade

When setting up the planetable, the tripod legs should be spread well apart and firmly pressed into the ground. The table should be about waist high, so that the operator can bend over it without resting against it. The board is leveled by placing the alidade near the center of the tabletop, loosening the tilting clamp, and tilting the board until the circular level bubble on the alidade is centered. The clamp is then tightened to hold it in this position. Care should be used to avoid having the alidade slide off the board when making this adjustment. Since few tables are sufficiently rigid to remain level as the alidade is shifted about, no special attempt is made to see that the board is perfectly level each time an observation is made.

In order to have the plotted angles theoretically correct, the plotted position of the station at which the planetable is set should be directly over the corresponding ground point. The degree of care to be used in bringing the plotted point over the ground point depends on the scale of the map.

For small scale map work the table is placed over the station without attempting to get the plotted point vertically over the ground point. On large scale mapping the table is set over the point approximately oriented by sighting or magnetic needle. Then by plumbing, the table is shifted bodily until the point on the paper is approximately over the station point.

The clamp that holds the table from rotating is now loosened and the table is oriented by rotating it on its vertical axis. Orientation may be done by various methods. For making rough, small-scale maps orientation by means of the magnetic compass is sufficiently exact. The table is rotated until the fixed bearing (usually magnetic north) is observed. It is then clamped and all mapping at the station is carried on without disturbing the board. If the compass is mounted on the alidade, the straightedge is aligned with a meridian that was drawn at the first station occupied, and the table rotated until the needle points north. Orienting with the magnetic needle has an advantage over other methods in that an error in the plotted direction of one line will not introduce a systematic error in lines plotted from succeeding stations. The disadvantages are inability to determine the exact point on the graduated arc at which the needle comes to rest; magnetic variations due to local attractions or other causes; and sluggish needles, bent pivots or bent needles.

The table can also be oriented by backsighting along an established line which has been previously plotted. The advantage of this method lies in the increased precision obtained in orientation. A disadvantage is that the error in any previously plotted line is transferred to succeeding lines. This is the method generally used on intermediate and large scale mapping.

The table can also be located by the application of the principle of resection. This method is used to determine the position of any point on the map corresponding to the location of the point on the ground over which the planetable is set. It is required that three established ground points can be seen from the point in question and that the positions of these three points have been located on the map. The direction of the magnetic meridian should be established on the sheet prior to attempting the solution of the 3-point problem so that the table can be oriented into the approximate correct position.

Assume the planetable is set up on an unmapped ground point D, and points A, B, and C whose positions a, b, and c are plotted on the sheet, are visible from D. The problem is to find the location of d on the sheet corresponding to D on the ground. This location of d is found by trial. The planetable is oriented by estimations at point D. See Figure 1-38.

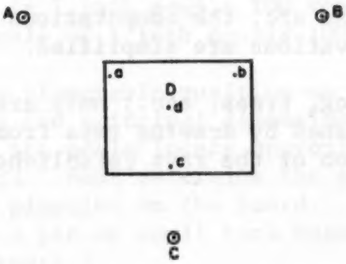


Figure 1-38 Location of a point on planetable

If this estimated orientation is correct, resection lines from A, B, and C would intersect at assumed point d. A resection line is drawn on the sheet with the edge of the alidade at point a and a sight taken on point A. Similar lines are drawn on the sheet with the edge of the alidade at b and c and sights being taken on B and C. As the table, however, was oriented at D by estimation, these resection lines will not intersect at point d, but will form a triangle of error a', b', c'. See Figure 1-39. The size of this triangle will depend on the degree of error in orientation.

Usually, after some experience, two attempts are sufficient to properly orient the planetable and find the plotting position of d. In estimating the correct position of the point on the sheet from the triangle of error, the following geometric relations, as illustrated in Figure 1-39, should be borne in mind:

1. When D is within the triangle, abc, the point d will fall within the triangle of error, and will be farther from the line from the furthermost point than from either of the lines from the other two points.
2. When D is outside the triangle abc but within the circle prescribed by the points of this triangle, d will fall outside the triangle of error, and is on the side of the line from the

middle point opposite the intersections of the lines from the other two points.

3. When D is outside the circle prescribed by the points of the triangle abc, d is outside the triangle of error and on the same side of the line from the most distant point as is the intersection of the lines from the other two points.

4. In every case, the distance of d from a resection line is proportional to the distance that D is from the point from which the resection line is drawn.

After orientation, the direction of lines are observed by rotating the alidade until the line of sight corresponds to the line to be observed. If stadia rods are used, the distance can be read and plotted to the scale of the map. Elevations can also be determined and plotted. If the alidade is equipped with a Beaman arc, the computations for true horizontal distance and corrected elevations are simplified.

If objects (building, trees, etc.) only are to be located, their position may be established by drawing rays from two previously plotted points. The intersection of the rays establishes the location of the objects.

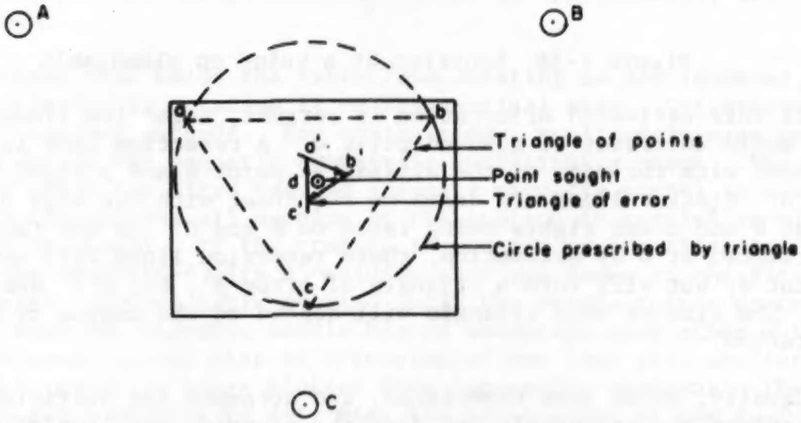


Figure 1-39 Triangle of error and geometric relationship to point sought (planetable)

Mapping Procedures

Mapping with the telescopic alidade and planetable consists of the following steps:

1. Set up the planetable on its tripod in a strategic location so that as large a part as possible of the area to be mapped is visible. Sufficiently accurate readings for average mapping can be taken up to 1,500 feet on cloudy days, less in bright

sunlight. Distances should not exceed 1,000 feet if elevations also are to be obtained. Heavy paper should be used on the drawing board, preferably of dull buff or green color in order to reduce glare.

2. Level the table with the bubble or bubbles provided on the base plate of the alidade. Tighten the upper clamp of the tripod head to secure the table in the horizontal plane.

3. Orient the table with the area to be mapped. If this is the initial setup, rotate the table around its vertical axis until the long axis lies in the same direction as the long axis of the area to be mapped. Then tighten the lower clamp which holds the table in position.

4. Select the scale for mapping. A suitable scale for most topographic mapping is 1 inch equals 200 feet. When greater detail is desired, a scale of 1 inch equals 100 feet may be adequate.

5. Next, locate the planetable position on the sheet of drawing paper. Estimate the principal dimensions of the area to be mapped and by means of the scale locate approximately its position on the drawing board. Next determine the approximate position of the planetable by a pinpoint on the board. (Use of a sewing needle is preferred to a pin or small tack because of its thinner taper and greater strength.)

6. With the alidade set in position, release the north arrow and rotate the alidade until the arrow comes to rest under the zero of its scale. The telescope is now pointed to magnetic north and the magnetic north line may be drawn on the map by use of the straightedge. This line is useful for rough orientation later and should be left on the map. Use a hard lead pencil (at least 4H) in planetable work. Moving the alidade around over the paper will smear a softer lead.

7. Plot points on the drawing board by the following procedure: Sight the telescope on a rod held at the selected point, keeping one edge of the straightedge against the needle which represents the map position of the instrument position on the ground. Observe the distance from the instrument to the point. Use an engineer's scale to measure this distance on the map along the line of sight and plot the point. Distances may be measured on the ground by pacing, chaining, or by stadia. Usually this measurement is by stadia rod set on points to be plotted on the map and observed on the vertical crosshair of the alidade. When elevations also are to be obtained, set the vertical hair on the rod, level the bubble tube, and read the middle crosshair and one of the stadia hair intercepts on the rod. The middle crosshair reading gives the elevation, and by multiplying the interval between the two rod readings by two the stadia interval is also obtained. One man can map faster than another can move around

to the points to be mapped. Thus a better balanced crew would make use of two rodmen.

8. A plan for the survey should precede survey work so that all necessary information will be obtained with a minimum of effort. If the area is to be gridded, and this is often the best way to obtain the necessary information, distances between shots can be measured by the rodman from pacing and the location of the point plotted on the map by the instrumentman. Care should be taken by the rodman to retest representative points for plotting contours.

9. After all information has been obtained for the setup, the instrument is moved to a new location. Before moving, take a foresight to the new location and plot the point on the map. Take an elevation turn about midway to the new setup. After moving the instrument to the new station and leveling up the table, orient the instrument by laying the straightedge along the line on the map from the new to the old instrument station and rotate the table until the vertical crosshair in the telescope falls on the rod held at the previous station. Again tighten the table clamp and the instrument is oriented. The HI is picked up by taking a backsight on the elevation turn set before the move. A set of differential level notes should be kept of the readings taken on bench marks and turning points, carefully describing each.

10. Should the location of instrument stations become lost either on the ground or on the map the planetable can be oriented as previously described on page 1-69 or by two or three different methods which are described in surveying texts.

Beaman Stadia Arc

To speed field work on sloping land where vertical angles are read, the Beaman Stadia Arc is a valuable time saver. If the instrumentman is skilled in its use, as many as three rodmen can be used.

Since the details of using the Beaman Stadia Arc may be unfamiliar to some field men, a discussion in its use is included herein. The Beaman Stadia Arc is an attachment to the vertical arc of a transit or to the planetable alidade. Its purpose is to simplify the reduction of inclined stadia observations to horizontal distances and elevations. The Beaman Stadia Arc is based on the principle that the difference in elevation between the height of the instrument and the point where the middle crosshair strikes the rod is a multiple of the rod interval between stadia hairs. Since these differences in elevations are normally expressed by vertical angles between the points, we know that it would be necessary to have the vertical angle between the points expressed so that the function of ½ sin $\underline{a}$ ($\underline{a}$ being vertical angle) is a multiple of the rod interval.

In the formula:

$$\text{Difference in elevation} = \frac{f}{i} \times \text{Rod Interval} \times \frac{1}{2} \sin \underline{2a},$$

where f = focal length of objective (the distance from the optical center to the crosshairs when the telescope is focused on a distant object) and i = the distance between the top and bottom crosshair of the instrument. The relationship between these two distances is expressed as the ratio $\frac{f}{i}$ in the above formula and is a constant for any given instrument having fixed crosshairs. This ratio is known as the stadia constant and is 100 for most instruments.

Using the above formula and selecting those vertical angles whose function of $\frac{1}{2} \sin 2\underline{a}$ is equal to .01, .02, .03, etc., up to .90 and with $\frac{f}{i} = 100$, the computed angles will represent the factors 1, 2, 3, etc., up to 90. These factors are represented on the V scale of the Beaman arc. Thus, the difference in elevation between the instrument height and the ground at the rod is equal to the rod interval times the V scale reading on the arc, plus or minus, the rod reading. The 50 on the V scale represents a 0° reading with plus vertical angles numbered from 50 up, and minus vertical angles numbered from 50 down. Therefore, whatever the reading, always subtract 50 from it and use the algebraic remainder.

The Beaman arc is also used in obtaining the correct horizontal distance between the instrument and the point at which the rod is held without time-consuming calculations.

Looking at the formula,

Horizontal distance = $\frac{f}{i}$ x rod interval x $\cos^2 \underline{a}$ and
Making $\cos^2 \underline{a} = .99, .98, .97$, etc., down to .80
with the corresponding angular values, we have

Horizontal distance = 100 x rod interval x .99 etc., down to .80.

These computed angles are laid off on the H scale of the arc from the same zero, and numbered consecutively 1 (100-99), 2 (100-98), 3 (100-97), etc., up to 20. The H scale reading is then used as the percentage correction to be subtracted from the rod reading to get the horizontal distance.

Example of the use of the Beaman Stadia Arc:

With the instrument set up and leveled, sight on the rod and read the space intercepted by the upper and lower crosshair (rod interval). Let this be 6.40 feet. On the V scale of the arc assume the index reads between 32 and 33. With the tangent screw, bring the nearest whole number on the scale even with the index. This can be 33. Read the elevation on the rod cut by the middle crosshair. Let this be 7.30 feet.

With the rod interval reading 6.40 we know it represents a distance of 640 feet. The V scales read 33 and the rod reading is 7.30. The desired multiple then is 33-50 = -17, and the vertical difference equals -17x6.40 = -108.8. The difference in elevation between the instrument and the base of the rod is then -7.30-108.8 = -116.1 feet. The minus sign indicates that the point at the rod is lower than the instrument.

The true horizontal distance is found by means of the H-scale which gives at the same pointing a direct reading of the percentage correction (always subtracted) necessary to reduce the observed stadia distance reading to the true horizontal distance. Thus in the above example you will note that on the H scale the index coincides with 3, or 3 x 6.40 = 19.2 feet and 640 feet - 19.2 feet = 620.8 feet, being the true horizontal distance. The (f+c) of the instrument should be added to this true horizontal distance. The (f+c) is the stadia constant and represents the distance from the plumb line center of the instrument to the point of outer focus. For practical purposes this is one, so that 1 foot can be added to the above calculated true horizontal distance.

An explanation of the notes in making a traverse survey with topography using the Beaman arc and planetable is given below.

The front sheet and subsequent sheets can be set up as shown in Figure 1-40. An explanation of the origin and use of the figures in each column of the notes follows:

1. 1st Column - Stadia Distance -- The stadia distance is obtained by reading the length of rod showing between the top and bottom crosshairs in the instrument. For example, the 4th distance in the example (700 feet) is measured by the 7.0 feet of rod showing between the top and bottom crosshairs.

2. 2nd Column - Horizontal Arc -- A horizontal correction per hundred feet of distance is determined from a direct reading of the H scale on the Beaman arc. For the example, this is between 1 and 2 or say 1.5. Total correction is then 7.0 x 1.5, or 10 feet to the nearest foot.

3. 3rd Column - Corrected Distance -- This distance equals 700 - 10 or 690 feet. Corrections are not shown for the other distances since these amount to about 1 foot or less. Corrections depend upon the degree of accuracy required.

4. 4th Column - Vertical Arc -- This is the vertical scale reading on the Beaman arc. The arc reads 50 when the telescope is level. Thus a reading above 50 shows the telescope tilted up and below 50 tilted down.

5. 5th Column - Product -- To obtain the numerical value of the product, the distance is multiplied by the numerical difference between the arc reading and 50. For example, with a distance of 635 feet (first reading) and an arc reading 52, the product would be 635 x 2 = 1270. Since the instrument is calibrated 1:100 the product becomes 12.7. To obtain the proper sign of the product, the following conditions will govern:-

a. On backsights

(1) Arc more than 50 - product is minus (-)
(2) Arc less than 50 - product is plus (+)

b. On foresights

(1) Arc more than 50 - product is plus (+)
(2) Arc less than 50 - product is minus (-)

In some cases with the telescope level the bottom or top hair may be on the rod and the center and other outside hair off the rod. The telescope must be tilted enough to place at least two crosshairs on the rod so as to obtain the distance, after which it can be brought back to level. The correction to be applied is determined by multiplying the distance by 1/2 or .5 and dividing this product by 100. The sign is determined by the set of rules stated above.

6. 6th Column - Rod -- The Beaman arc is set on some even division so that the center crosshair falls on the rod. The rod reading is then the reading of the center crosshair on the rod. The only exception is on half Beaman arc shots where the rod reading is obtained by reading either the top or bottom crosshair. The sign that applies to the rod reading is the same as in differential leveling. All backsights are plus (+) and all foresights are minus (-).

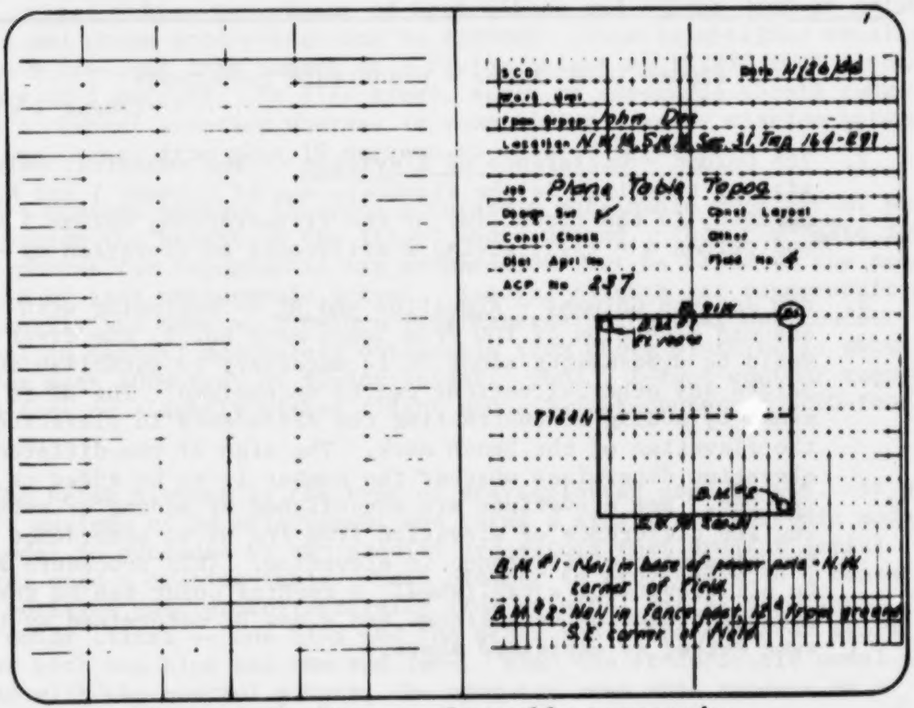
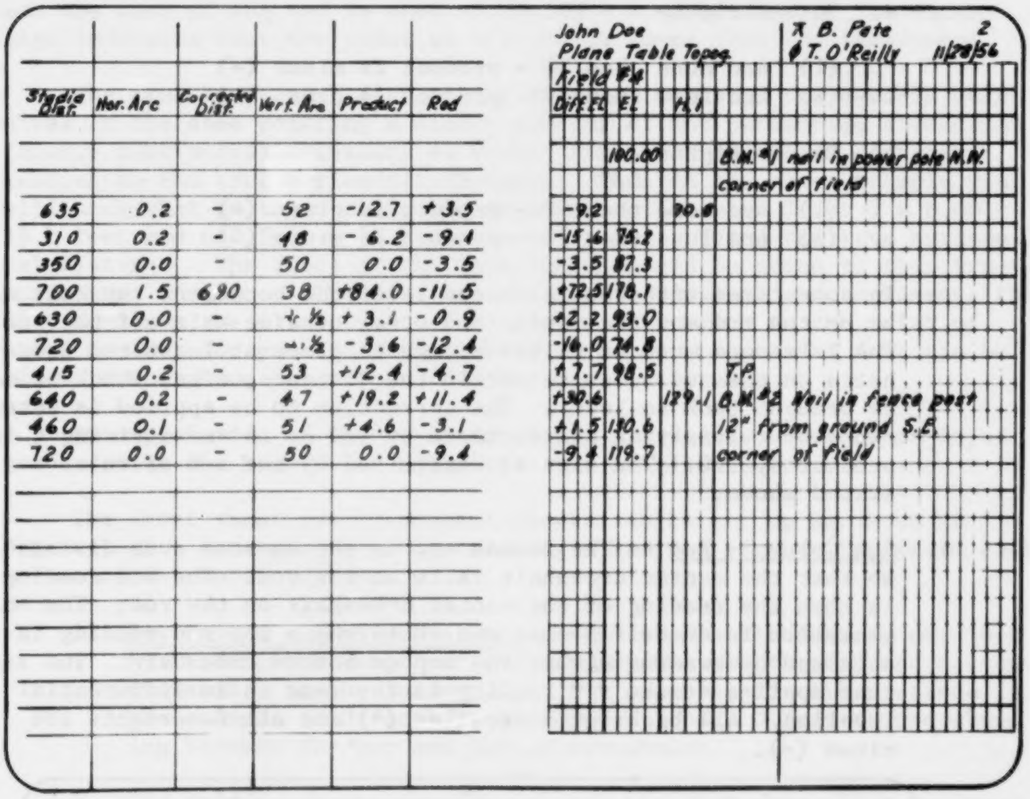

1
John Doe
Sec. 31, Twp. 164-R91
Plane Table Topog
✓
4
237
T164N
B.M. #1 - Nail in base of power pole - N.W. corner of field
B.M. #2 - Nail in fence post, 1/2' from ground S.E. corner of field

Figure 1-40 Notes - planetable topography
(sheet 1 of 2)



John Doe
Plane Table Topog.
Field #4

⊼ B. Pete
ɸ T. O'Reilly
2
11/28/56

Stadia Dist.	Hor. Arc	Corrected Dist.	Vert. Arc	Product	Rod	Diff. El.	El.	H.I.	
							100.00		B.M. #1 nail in power pole N.W.
									corner of field
635	0.2	-	52	-12.7	+3.5	-9.2		90.8	
310	0.2	-	48	-6.2	-9.4	-15.6	75.2		
350	0.0	-	50	0.0	-3.5	-3.5	87.3		
700	1.5	690	38	+84.0	-11.5	+72.5	178.1		
630	0.0	-	+ ½	+3.1	-0.9	+2.2	93.0		
720	0.0	-	- ½	-3.6	-12.4	-16.0	74.8		
415	0.2	-	53	+12.4	-4.7	+7.7	98.5		T.P.
640	0.2	-	47	+19.2	+11.4	+30.6		129.1	B.M. #2 Nail in fence post
460	0.1	-	51	+4.6	-3.1	+1.5	130.6		12" from ground S.E.
720	0.0	-	50	0.0	-9.4	-9.4	119.7		corner of field

Figure 1-40 Notes - planetable topography
(sheet 2 of 2)

7. 7th Column - Difference of Elevation -- The numerical value and sign of this item is the algebraic sum of columns 5 and 6. For example, in the first line of the illustration, column 5 = -12.7 and column 6 = +3.5, giving a difference of elevation of -9.2.

8. 8th and 9th Columns - Elevation and HI -- Beginning with an assumed elevation of 100 from bench mark No. 1, the first shot would be a backsight since it is necessary to establish an HI before any other elevations can be determined. The HI is determined by adding or subtracting the difference in elevation from the elevation of the bench mark. The sign of the difference in elevation determines whether the number is to be added or subtracted. New elevations are established by adding or subtracting the difference of elevation from the HI in accordance with the sign of the difference in elevation. This procedure applies to all elevations established. A turning point can be taken on any new elevation established and a new HI determined by the same method as explained above.

Advantages of the Beaman Stadia Arc:

1. It eliminates the need for stadia tables, slide rules or diagrams.
2. There is no vernier to read.
3. Accuracy of results are identical for formula or table computations.
4. Chances of errors are practically eliminated because of its simplicity.

TOPOGRAPHIC SURVEYS BY AERIAL PHOTOS, GROUND CONTROL SURVEYS AND STEREOPLOTTER

Topographic surveys can be made economically by use of aerial photos, ground control surveys and stereoplotter. Aerial photos must be studied to select identifiable image points suitable for making vertical and horizontal control measurements used to scale the plotter stereoscopic models. The stereoscopic models are the areas covered by two overlapping, or stereo pair of photos. The control points must be positively identified in the field, identified and marked on the photos, and easily seen in the stereoscopic model.

The scale of the aerial photo is the ratio of the camera focal length to the height of the flight above ground. Scale of photos generally used by the United States Department of Agriculture and by the SCS in soils surveys and photo interpretations is 1:20000. This is obtained usually with an 8 1/4-inch lens camera at a flying height of 13,750 feet within an accuracy of 5 percent. In flat areas, scale of exposures should range within 3 percent accuracy whereas in mountainous areas variation between photos may range from plus 10 percent to minus 20 percent.

The minimum contour interval accurately obtainable from aerial photos depends upon the height of the flight above ground. Thus the scale for aerial photos for topographic map preparation must be based on the accuracy required by each topographic survey. Special flights for topographic mapping usually are made with 6-inch lens cameras. The smallest contour interval (C factor) accurately obtainable from photo plotting is about 1 foot for each 1000 feet of flying height. Thus a 2-foot contour requires a 2000-foot or slightly higher flight and a 5-foot contour a 5000-foot height.

The Kelsh plotter is the type of stereoplotter used by SCS. It provides a maximum of 5x enlargement and forms a single stereoscopic model. This model is produced by two precise projectors that project aerial pictures onto a tracing table. Each plotter is provided with a contact glass positive made photographically from original aerial negatives. Each has a color filter -- one blue and the other red. The operator wears glasses with one blue and one red lens. When the stereoscopic model is aligned with the control points, the operator sees what appears as a floating dot of light on the elevation to be traced. This light comes through a pinhole in the center of the tracing table platen, which is a white disk about 3 inches in diameter. The operator keeps the dot on the ground as he moves the tracing table and an attached pencil traces the contour from below.

Setting up the stereoscopic model in the plotter requires horizontal and vertical ground control. The base line measurement for horizontal control must be made on the ground between two clearly identifiable points on the photos within the area of the model. The base line should be long enough to measure 3 or more inches on the contact photo and be located within a flat area of topography on the photo. Base line measurements should be provided for about every third or fourth model. Four vertical control points, one near each corner, also are required for each model. Depending on the accuracy required, differential leveling or trignometric leveling is used to determine elevation of the 4 vertical control points.

The following illustrates the survey requirements for establishing the vertical and horizontal ground controls for Kelsh plotting for less than 5-foot contour intervals:

1. Indicate on photos, by red circles, points at which differential elevations and measured distances are needed in order to level and scale the model(s) of the area to be plotted by Kelsh plotter.

2. Obtain one vertical elevation somewhere within each of the red circled areas. The point selected should be on an area which is as flat and level in all directions as is possible to find. In most cases, the point itself will not be exactly identifiable on the photos, so it will be necessary to locate its position by measurement to objects which are visible on the photo. These objects should be described, and pricked and circled on the front of the photo. The vertical control point selected should be in an area that has not been significantly disturbed or changed in elevation since the photos were taken. Points should not be selected in the shadow of a tree or building. Roads, areas of dense vegetation, and very light or dark areas on the photo are poor points for elevations.

3. In some cases, it may be necessary to chain long distances from the vertical elevation point selected in order to find objects which are identifiable on the photograph, but make sure that all points used are in the stereoscopic overlap area of one stereo pair. A stereoscope should be used to find and identify these points.

Examples of identifications sometimes used are shown on Figure 1-41.

Diagrams to clarify description should be drawn when necessary. These need not be to scale. Measurements should not be made from indefinite objects which cannot be pinpointed on the photo.

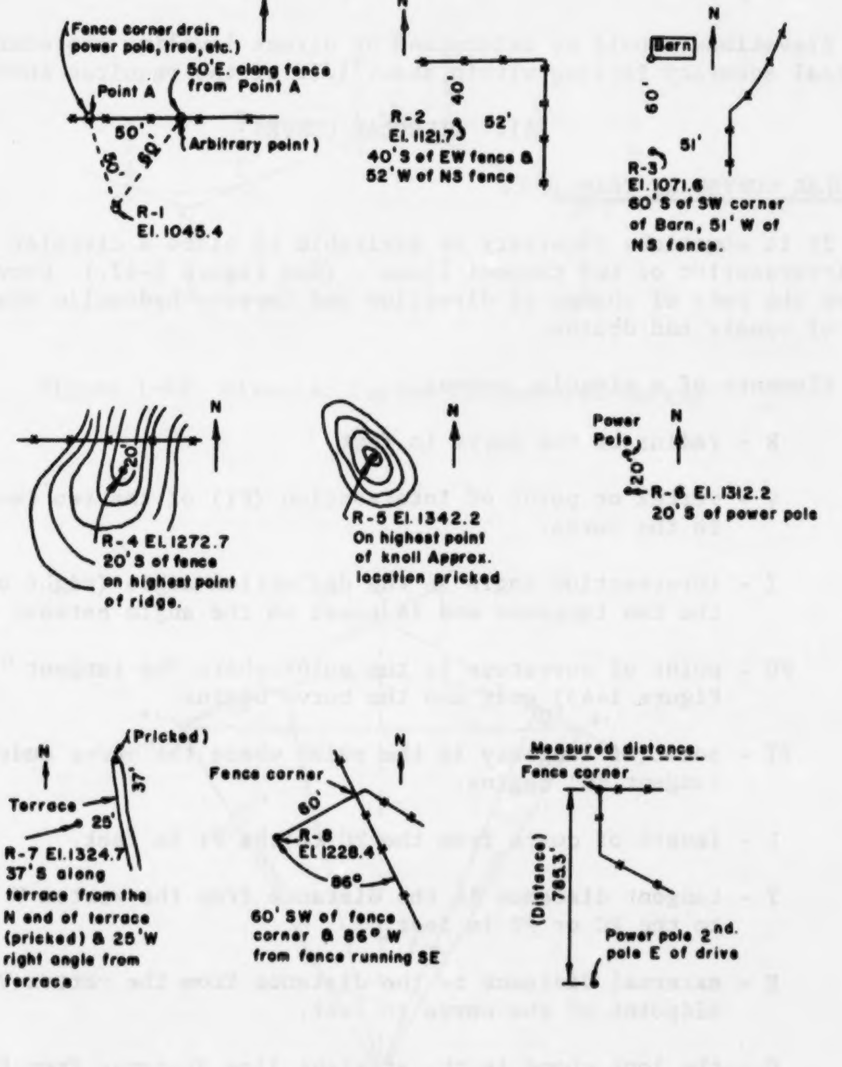

N
(Fence corner drain power pole, tree, etc.)
50'E. along fence from Point A
Point A
50'
60'
50'
(Arbitrary point)
R-1 El. 1045.4
N
40'
R-2 El. 1121.7
52'
40'S of EW fence & 52'W of NS fence
N
Barn
60'
51'
R-3 El. 1071.6 60'S of SW corner of Barn, 51' W of NS fence.
N
20'
R-4 El. 1272.7 20'S of fence on highest point of ridge.
N
R-5 El. 1342.2 On highest point of knoll Approx. location pricked
Power Pole
N
20'
R-6 El. 1312.2 20'S of power pole
(Pricked)
N
37'
Terrace
25'
R-7 El. 1324.7 37'S along terrace from the N end of terrace (pricked) & 25'W right angle from terrace
N
Fence corner
60'
R-8 El. 1228.4
86°
60' SW of fence corner & 86° W from fence running SE
N
Measured distance
Fence corner
(Distance) 785.3
Power pole 2nd. pole E of drive

Figure 1-41 Examples - identification of ground control points for stereoplotter

The use of N, S, SE, SSW, etc., in the description of a point will be assumed to be approximate or general. If directions are measured in the field with a compass or transit, they should be expressed in degrees of angle from a line visible on the photograph, such as a road, fence, etc. Measured distances may vary from about 600 to 1000 feet or more and should be chained. Both terminals of the chained distances should be pricked and circled on the front of the photograph and described on the back of the photo. They must fall in the stereoscopic overlap area of one stereo pair.

Elevations should be determined by direct leveling procedures, with vertical accuracy falling within about 1/10 of the required contour interval.

11. CIRCULAR CURVES

CIRCULAR CURVES BY TRANSIT

It is sometimes necessary or desirable to place a circular curve at the intersection of two tangent lines. (See Figure 1-42.) Curves help reduce the rate of change of direction and improve hydraulic characteristics of canals and drains.

Elements of a circular curve:

R - radius of the curve in feet.

V - vertex or point of intersection (PI) of the two tangents to the curve.

I - intersection angle is the deflection angle (right or left) of the two tangents and is equal to the angle between the radii.

PC - point of curvature is the point where the tangent "A" (see Figure 1-43) ends and the curve begins.

PT - point of tangency is the point where the curve ends and the tangent "B" begins.

L - length of curve from the PC to the PT in feet.

T - tangent distance is the distance from the vertex V (or PI) to the PC or PT in feet.

E - external distance is the distance from the vertex V to the midpoint of the curve in feet.

C - the long chord is the straight line distance from the PC to the PT in feet.

M - middle ordinate is the distance from the midpoint of the curve to the midpoint of the long chord in feet.

D - the degree of curve is that angle at the center subtended by a chord of 100 feet.

d - angle at center subtended by a subchord

c - chord or subchord

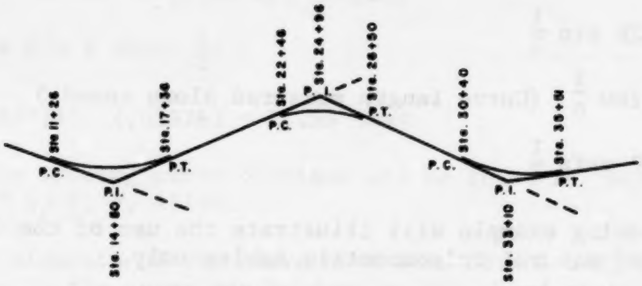

Sta 11+28
P.C.
P.I.
Sta. 14+80
Sta. 17+36
P.T.
Sta. 22+48
P.C.
P.I.
Sta. 24+86
Sta. 26+50
P.T.
Sta. 30+40
P.C.
P.I.
Sta. 33+10
Sta. 35+10
P.T.

Figure 1-42 Circular curves in traverse survey

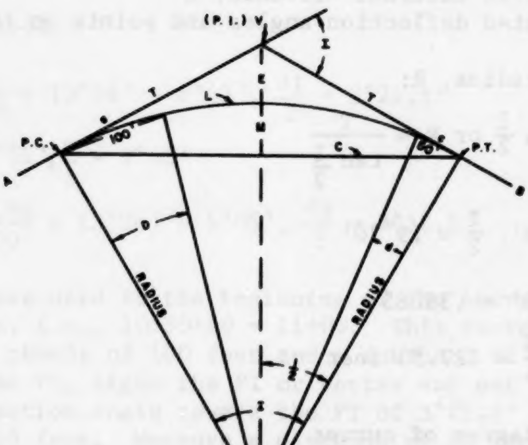

(P. I.) V
I
T
T
L
E
M
100'
C
P.C.
P.T.
A
B
D
RADIUS
RADIUS
I

Figure 1-43 Elements of circular curve

The following relationships exist between the various curve elements:

$T = R \tan \frac{I}{2}$

$E = R \text{ exsec } \frac{I}{2}$

$\sin \frac{1}{2} D = \frac{50}{R}$

$C = 2R \sin \frac{I}{2}$

$L = 100 \frac{I}{D}$ (Curve length measured along chords)

$M = R \text{ vers } \frac{I}{2}$

The following example will illustrate the use of the foregoing formulas with the use of natural trigonometric tables only.

Example

Given: Intersection angle $I = 38°40'$; tangent distance $T = 150.0$ feet.

Find:
1. Radius, R
2. Degree of curve, D
3. Length of curve, L
4. Computed external distance, E
5. Computed deflection angles and points on the curve

1. To find Radius, R:

$T = R \tan \frac{I}{2}$ or $R = \frac{T}{\tan \frac{I}{2}}$

$I = 38°40'$, $\frac{I}{2} = 19°20'$

$\tan 19°20' = .35085$

$R = \frac{150.0}{.35085} = 427.53$ feet

2. To find degree of curve:

$\sin \frac{1}{2}D = \frac{50}{R} = \frac{50}{427.53} = .11695$

$\frac{1}{2}D = 6°43'$

$D = 13°26'$

3. To find length of curve, L:

$$L = 100 \times \frac{38.66^\circ}{13.43^\circ} = 287.86 \text{ feet}$$

Note: The length of curve may also be found by the formula $L = RI$, where the angle I is in radians. This length will be slightly longer and more precise, as it represents the true arc length.

4. Since $E = R \text{ exsec } \frac{I}{2}$:

$$E = 427.43 \ (.05976) = 25.55 \text{ feet}$$

Tables for solving curve problems may be found in "Railroad Curves and Earthwork" by C. F. Allen.

When the elements of the curve have been calculated, the actual fieldwork of laying in the curve may be done by the chord stationing method or by the arc method. The chord stationing method will be explained here.

The first step in the field location of a curve is to mark on the ground the PC and PT locations (by measuring on line from the vertex or PI). The calculation of the deflection angle for a 100-foot chord and subchords (less than 100 feet) should then be made. The deflection angle for a 100-foot chord is $\frac{D}{2}$ and for a subchord it may be found by proportion.

See Figure 1-44.

$$d_1 = \frac{50}{100} \times 13^\circ 26' = 6^\circ 43', \ \frac{d_1}{2} = 3^\circ 21.5'$$

$$D = 13^\circ 26', \frac{D}{2} = 6^\circ 43'$$

$$d_2 = \frac{37.86}{100} \times 13^\circ 26' = 5^\circ 05', \ \frac{d_2}{2} = 2^\circ 32.5'$$

A subchord was used at the beginning of the curve to make the stationing come out even; i.e., 10+50+50 = 11+00. This curve could have been run in with two full chords of 100 feet and a subchord of 87.86 feet. With the transit set on the PC, sight the PI or vertex and set the vernier on 0°00'. Then turn a deflection angle toward the PT of 3°21.5' (See Figure 1-44) for the subchord of 50 feet. Measure a distance of 50 feet from the PC to the point on the curve. A flagged nail is commonly used to identify each point where the line of sight intersects the curve centerline. From the PC (station 10+50) the point would fall at station 11+00 on the curve. (See Figure 1-44.) For the next full chord of 100 feet an additional 6°43' is added to 3°21.5' to give an accumulated deflection of 10°04.5' from the tangent line. A distance of 100 feet is measured from station 11+00 on the curve to the intersection of the line of sight and the curve centerline (station 12+00). This point is also marked.

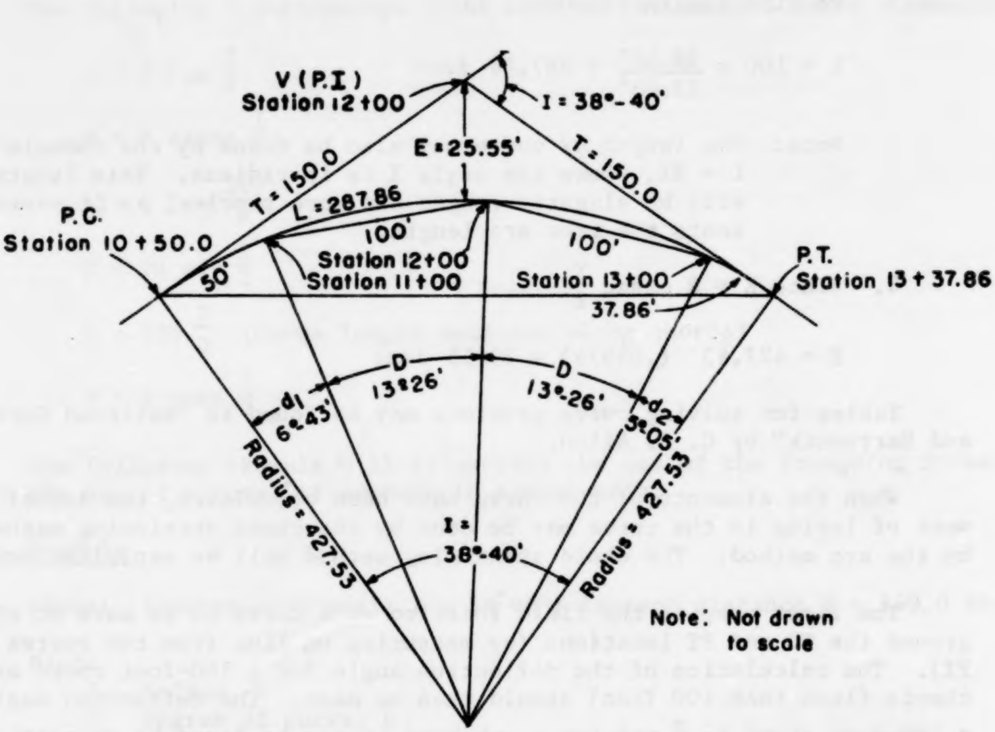
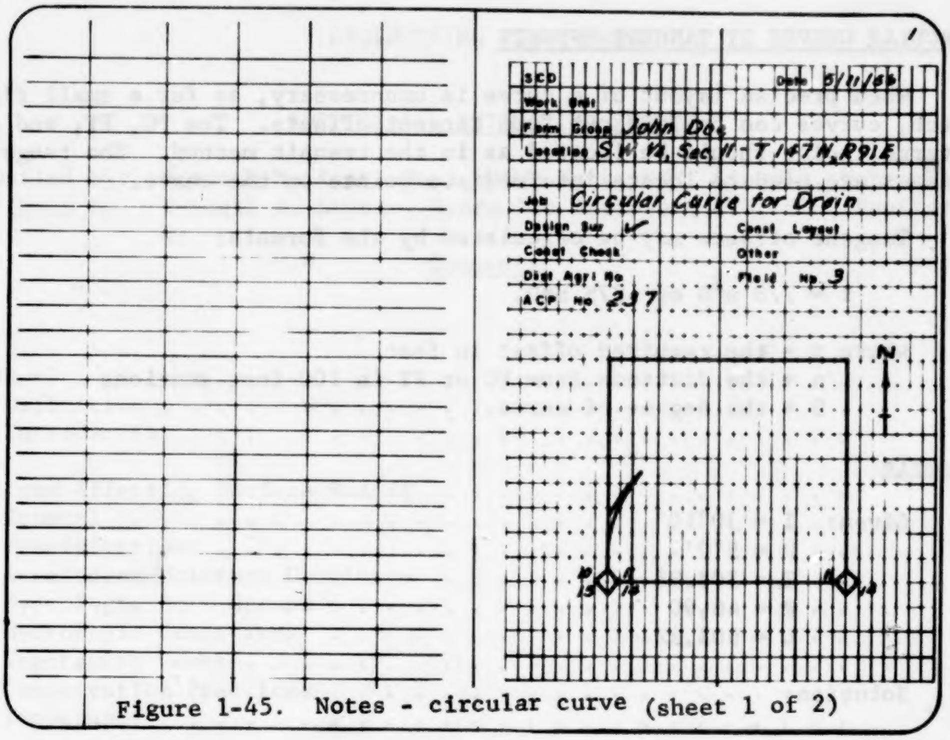

V (P.I)
Station 12+00
I = 38°-40'
E = 25.55'
T = 150.0
T = 150.0
L = 287.86
P.C.
Station 10 + 50.0
100'
100'
50'
Station 12+00
Station 11+00
Station 13+00
P.T.
Station 13 + 37.86
37.86'
D
D
13°26'
13°-26'
d1
6°43'
d2
3°05'
Radius = 427.53
Radius 427.53
I =
38°-40'
Note: Not drawn
to scale

Figure 1-44 Layout of circular curve

The next deflection angle is also 6°43' as the chord is 100 feet long. The additional 6°43' is turned giving a total deflection from the tangent line of 16°47.5'. A distance of 100 feet is measured from station 12+00 to station 13+00 on the curve, and marked. The last deflection angle for this curve is for the subchord of 37.86 feet and is 2°32.5' (See Figure 1-44) and when added to 16°47.5' gives a total deflection of 19°20'. This angle when turned from the tangent line to the PT while the transit is on the PC should be equal to $\frac{I}{2}$; i.e., $\frac{38°40'}{2}$ = 19°20' and is a check on deflection angle calculations.

See Figure 1-45 for notes on layout.



1

SCD Date 5/11/56

Work Unit

Farm Group John Doe

Location S.W. 1/4, Sec. 11 - T 147 N, R 91 E

Job Circular Curve for Drain

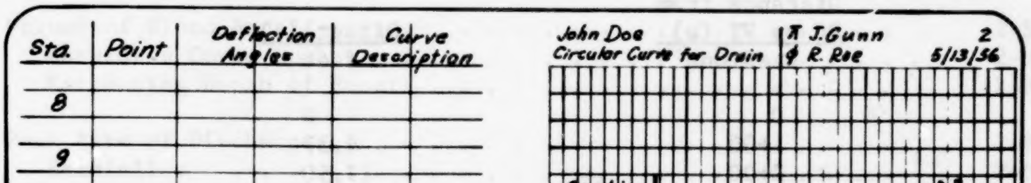
Design Sur ✓ Const Layout

Const Check Other

Dist Agr'l No Field No. 9

ACP No. 237

Figure 1-45. Notes - circular curve (sheet 1 of 2)



Sta.	Point	Deflection Angles	Curve Description
8			
9			
9+15.4	Section Corner		
10			D = 13°26'
10+50	P.C.	0.00'	R = 427.5 L = 287.9
11		3°-21.5'	T = 150.0 I = 38°-40'
12	P.I.	10°-04.5'	
13		16°-48.5'	
13+37.9	P.T.	19°-20'	
14			
15			

John Doe
Circular Curve for Drain

⊼ J. Gunn
⊄ R. Ree

2
5/13/56

Section Line
N
P.T.
38°40'
P.I.
P.C.
Section Corner
10
15
11
14

Figure 1-45. Notes - circular curve (sheet 2 of 2)

CIRCULAR CURVES BY TANGENT OFFSETS

When precise layout of a curve is unnecessary, as for a small field ditch, curves can be laid out from tangent offsets. The PC, PT, and the external point should be located as in the transit method. The tangent offsets are used to locate intermediate points on the curve.

Tangent offsets may be calculated by the formula:

$$z = 7/8\ n^2D \text{ or } .875\ n^2D.$$

where z = the required offset in feet
n = the distance from PC or PT in 100-foot stations
D = the degree of curve.

Example

Given: $I = 30°10'$
$D = 5°0'$
$T = 308.93$
$E = 40.90$
$L = 603.32$

Solution:

Distance from PC or PT (n) stations	Offset (z) feet
0	0
1+00	4.37
2+00	17.50
2+50	27.34

Measure the stations from the PC and PT along the tangents toward the PI and offset at right angles the distances shown in the table. (See Figure 1-46). Since the tangent distance of this curve is slightly over 300 feet, the above points are adequate. Chain from the PC to determine the stationing of these stakes on the curve.

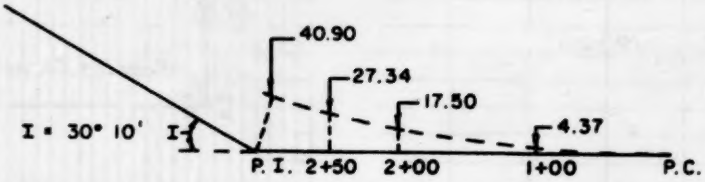


Figure 1-46 Curve layout by tangent offsets

ENGINEERING FIELD MANUAL

CHAPTER 2. ESTIMATING RUNOFF

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1/ ES-1026 and ES-1029 are not included in the national distribution of Chapter 2, Engineering Field Manual. Users requiring peak rates of discharge from ES-1026 and/or ES-1029 may obtain these graphs from the Western Regional Technical Service Center, SCS, Portland, Oregon.

ENGINEERING FIELD MANUAL

CHAPTER 2. ESTIMATING RUNOFF

1. GENERAL

DEFINITION

Estimating runoff is the process of determining the volume or peak rate of runoff, from a given watershed for the design storm, or the safe yield expected from the watershed.

INTRODUCTION

This chapter establishes procedures for estimating depth and peak rates of runoff and annual and seasonal yield from small watersheds for use in designing soil and water conservation measures.

The procedures for determining yield and peak rates are applicable to drainage areas of 5 to 2,000 acres in the United States, Puerto Rico and the Virgin Islands.

Tables and charts are included for a quick and reliable way to estimate peak rates of discharge and associated runoff volumes for a range of rainfall amounts, soil types, land use, cover conditions and average watershed slope. The data for the peak rate discharge charts were computed using procedures from the SCS National Engineering Handbook Section 4, (NEH4).(1) NEH-4 should be used to estimate peak discharge rates for conditions beyond the limits of the peak rate discharge charts, ES 1026, 1027, 1029 and for special situations and areas where procedures of this chapter may be considered too general to provide good estimates.

2. FACTORS AFFECTING SURFACE RUNOFF

GENERAL

Precipitation, whether it occurs as rain or snow, is the potential source of water that may run off the surface of small watersheds. The kind of soil and the type of vegetation growing in it have a major effect on the amount of precipitation that runs off. Mechanical treatment on a watershed, along with its topography and shape, affect the rate at which water runs off. The combined effect of soil, vegetative cover and conservation practices on the amount of rainfall that runs off the watershed are represented by "runoff-curve numbers" (CN's).

PRECIPITATION

The highest rates of runoff from small watersheds are usually caused by intense rainfall. The intensity of rainfall affects the rate of runoff more than it does the volume of runoff. The melting of accumulated snow in the mountains and northern plains may result in a greater volume of runoff, but usually at a lesser rate than runoff caused by rainfall. The melting of a winter's snow accumulation over a large area may cause major flooding along rivers. Intense rainstorms that produce high rates of runoff in small watersheds usually do not extend over a large area. Therefore, the same intense rainstorm that causes flooding in a small tributary is not likely to be the one that will cause major flooding in a main stream that drains several hundred square miles.

The intensity of rainfall varies considerably during the storm period. Three typical 24-hour storm distributions, Type IA, Type I, and Type II were developed from U. S. National Oceanic and Atmospheric Administration (Weather Bureau) data. They are associated with climatic regions. Type IA maximum intensities are less than Type I, and Type I intensities are less than Type II. Type IA and I storm distributions are typical of maritime climates with wet winters and dry summers. The Type IA storm distribution is characteristic of the coastal side of the Cascade and Sierra Nevada Mountains in Oregon, Washington, and Northern California, and for the coastal regions of Alaska. The Type I is the characteristic storm distribution for the coastal side of the Sierra Nevada Mountains in Southern California, and for Hawaii and the interior regions of Alaska. The Type II storm distribution is typical of the more intense storms that occur over the remainder of the United States, Puerto Rico and the Virgin Islands. Exhibit 2-9 is a map delineating the various regions where each storm distribution applies in the Pacific coast states.

The length of the most intense rainfall period contributing to the peak runoff rate is related to the time-of-concentration for the watershed in question. Only 17 minutes of the most intense storm period may contribute to the peak discharge of a small (10-acre) watershed with a 10-minute time-of-concentration, as compared to 17 hours contributing to the peak for a 2,000-acre watershed having a 10-hour time-of-concentration. The 24-hour rainfall duration, divided into 15- and 30-minute periods of intensity, was used to make up the Type I, Ia, and II storms in order to effectively extend across this wide range of time-of-concentration. Exhibits 2-3, 2-4, 2-5 and 2-6 are reproduced from the U. S. Weather Bureau Rainfall Frequency Atlases. (2)(3)(4)(5)

The annual peak rate of runoff may occur in some years from rainfall of moderate intensity falling on snow or coming soon after the spring snowmelt when the soil is cold and saturated. This is typical of some intermountain regions of the Northern states. In this case, special procedures may be necessary. The intensities would be like Type I for a maritime climate and runoff curve numbers would be adjusted to AMC III, according to Chapter 10, NEH-4.(1)

ANTECEDENT MOISTURE CONDITION

The amount of precipitation occurring in the five days preceding the storm in question is an indication of the antecedent moisture condition (AMC) of the soil. The runoff curve numbers (CN's) in Exhibits 2-2, 2-10, 2-11, and 2-12, are for an average antecedent moisture condition (AMC II). The average is based on the accumulated 5-day antecedent rainfall. If it is between 1.4 and 2.1 inches during a growing season or between 0.5 and 1.1 inches during a dormant season, the AMC is considered average. If the AMC is greater than 2.1 or 1.1 inches respectively, a wet antecedent moisture condition (AMC III) is presumed. If it is less than 1.4 or 0.5 inches respectively, a dry antecedent moisture condition (AMC I) is presumed. This is explained in Chapter 4, NEH-4.(1)

HYDROLOGIC SOIL GROUPS

Over 8,000 soils have been classified into four hydrologic soil groups as shown in Exhibit 2-1. The hydrologic soil groups, according to their infiltration and transmission rates, are:

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted. These consist chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission in that water readily passes through them.

B. Soils having moderate infiltration rates when thoroughly wetted. These consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

HYDROLOGIC CONDITIONS

The soil and its hydrologic condition, in most cases, affect the volume of runoff more than any other single factor. The hydrologic condition of the soil is determined by its moisture content at the time of the storm, its humus and organic content and its temperature, and whether or not it is frozen.

The 5-day antecedent rainfall described above under precipitation is an indicator of the moisture content of the soil. Runoff curve numbers (described later) can be increased or decreased to estimate extreme high and low volumes of runoff, according to the procedure in Chapter 10, NEH-4.

The spring snowmelt in the mountains may saturate the soil to the extent that early spring rains of a lesser amount than subsequent summer storms may cause the highest rate and volume of runoff for the year.

Crop residues tilled into the soil and the residual root system from grasses that have been in crop rotations produce a good hydrologic condition, thereby reducing the volume of runoff.

Low soil temperatures during the colder seasons decrease the rate of infiltration and thereby increase the volume of runoff to be expected. Rains on frozen ground may cause the greatest runoff of the year.

VEGETATIVE COVER

Vegetation affects runoff in several ways. The foliage and its litter maintain the soil's infiltration potential by preventing the sealing of the soil surface from the impact of the raindrops. Some of the raindrops are retained on the surface of its foliage, increasing their chance of being evaporated back to the atmosphere. Some of the intercepted moisture is so long draining from the plant down to the soil that it is withheld from the initial period of runoff. Another effect is the transpiration of soil moisture from previous rains leaving a greater void in the soil to be filled. Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land. This lengthens its time-of-concentration and reduces its peak discharge rate.

A good vegetative cover exists in grassland if it covers 75 percent or more of the ground. A poor vegetative cover exists if it covers less than 50 percent of the ground. Grass cover is evaluated on basal area of the plant, whereas trees and shrubs are evaluated on the basis of canopy cover.

CONSERVATION PRACTICES

Conservation practices, in general, reduce sheet erosion and thereby maintain an open structure of the soil surface. This reduces the volume of runoff but the effect diminishes rapidly with increase in storm magnitude.

Contouring and terracing reduce sheet erosion and increases the amount of rainfall withheld from runoff by the small reservoirs they form. Closed-end level terraces act as a storage reservoir without a spillway. Land areas in which level terraces have been constructed may be excluded from the drainage area above downstream measures if they have enough capacity to store the depth of runoff commensurate with the frequency of the measure in question. Gradient terraces increase the distance water must travel and thereby increase the time-of-concentration. This, in turn, reduces the peak rate of discharge.

TOPOGRAPHY

The slopes in a watershed have a major effect on the rate of runoff and the peak discharge rate at downstream points. Slopes have little effect on how much of the rainfall will run off.

Small potholes may trap an initial amount of rain, thus reducing the amount of expected runoff.

If large pothole and marshland areas make up one-third or less of the total drainage and do not intercept the drainage from the remaining two-thirds, they will not contribute much to the peak discharge rate. These areas may be excluded from the drainage area for estimating peaks. If these areas constitute more than one-third of the total area or if they intercept the remaining area, they will increase the time period during which the runoff moves through the watershed and concentrates at its outlet. Lengthening the time-of-concentration reduces the peak discharge rate. The volume of runoff may not be any less due to these conditions because the water in the potholes and marshlands may eventually drain to the watershed outlet. The pothole areas may increase the total volume of runoff if they are full from previous rain.

Topography affects the shape of the watershed. The ratio of the length (ℓ) of the mainstream to the average width (w) of a watershed may be referred to as its shape-factor (ℓ/w). An increase in the shape-factor value causes a reduction of the peak discharge rate due to the longer time-of-concentration, and vice-versa. Peak discharge rates in Exhibits 2-10, 2-11 and 2-12 were based on an average shape-factor of 160 Agricultural Research Service experimental watersheds.(7) The shape-factor for these watersheds varied with drainage size as follows:

$$\ell/w = a^{0.2} \text{ .... (Eq. 2-1)}$$

Where: ℓ = hydraulic length of watershed in feet

w = average width of watershed in feet

(or w = watershed area in square feet divided by ℓ in feet.)

a = watershed area in acres

If the small watersheds of a particular region within a state are exceptionally long and narrow, their shape-factor (ℓ/w) will be a larger figure than that obtained by Equation 2-1. Therefore the actual peak discharge would be smaller for this region than that given in Exhibits 2-10, 2-11 and 2-12. The State Conservation Engineer may choose to develop an adjustment factor for a region or have the peak computed manually for an individual watershed if the shape-factor is more than 50 percent greater than that obtained by equation 2-1. An adjustment may be determined by following the procedures in SCS-TP-149.

3. VOLUME OF FLOOD RUNOFF

WATERSHED CURVE NUMBERS

The SCS runoff equation is:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \text{ .... (Eq. 2-2)}$$

Where: Q = accumulated volume of runoff in inches depth over the drainage area.

P = accumulated rainfall in inches depth over the drainage area.

Ia = initial abstraction including surface storage, interception by vegetation and infiltration prior to runoff, in inches depth over the drainage area.

S = potential maximum retention of water by the soil in equivalent inches depth over the drainage area.

Since the potential maximum water retention can range from zero on a smooth impervious surface to infinity in deep gravel, the "S-values" were converted to runoff curve numbers (CN's) for greater convenience by the following transformation:

$$CN = \frac{1000}{10 + S} \quad \ldots\ldots\ldots\ldots\ldots \text{(Eq. 2-3)}$$

This narrowed the range of CN's to between 100 and near zero respectively since according to Equation 2-3 the CN is 100 when S is zero and approaches zero as S approaches infinity for deep sandy soils.

The runoff curve numbers for various watershed conditions previously described are listed in Exhibit 2-2. The CN's in this exhibit are for an average antecedent moisture condition (AMC II). A weighted curve number and peak runoff interpolation for a watershed can be estimated as shown in Example 2-3.

ESTIMATING DEPTH OF RUNOFF

The volume of runoff from a watershed may be expressed as the average depth of water that would cover the entire watershed. The depth is usually expressed in inches. Exhibit 2-7 lists the runoff depth in inches for a range of rainfall depths and CN's. One-day or 24-hour rainfall depths are shown in Exhibits 2-3, 2-4, 2-5 and 2-6. Rainfall depths for other durations may be obtained from the U. S. Weather Bureau Atlases. (2)(3)(4)(5) Note, however, that durations other than 24-hour should not be used for estimating peak discharge from Exhibits 2-10, 2-11 and 2-12. Step (3) in Example 2-2 illustrates the use of Exhibit 2-7 for obtaining depth of runoff.

4. PEAK RATE OF DISCHARGE

RAINFALL

The 24-hour rainfall depths for a desired location and frequency can be obtained from the appropriate map in Exhibits 2-3, 2-4, 2-5 and 2-6. The 24-hour duration must be used with the ES-1026, 1027 and 1029 Peak Discharge Charts in Exhibits 2-10, 2-11 and 2-12. The rainfall values for the eleven western conterminous states can be obtained from the U. S. Weather Bureau revised TP-40 maps for each state.

AVERAGE WATERSHED SLOPE

The average watershed slope, which is the slope of the land and not the watercourse, is available at most work unit locations from existing soil survey data. The hillside slopes can be measured with an Abney level in the direction of overland flow and averaged to obtain the watershed slope. This slope can be estimated accurately enough by SCS personnel familiar with the area to place it in one of the three categories - Flat, Moderate or Steep - in Table 2-1. It may be necessary to determine the average slope of the watershed within a greater degree of accuracy in order to obtain a closer estimate of the peak discharge for special measures. In this case, the peak discharge for a specific slope can be interpolated on log-log graph paper as demonstrated in Figure 2-1, for Examples 2-2 and 2-3.

Table 2-1 Slope factors for peak discharge

Slope Factor	**Average Slope Range in percent**	**Actual Slope Used in ES-1026 and 1027 Computations, in percent**
Flat[1]	**0 - 3**	**1**
Moderate	**3 - 8**	**4**
Steep	**8 and above**	**16**

---

[1] Level to nearly level.

PEAK DISCHARGE

The peak discharge can be obtained from the Peak Rates for Discharge charts, ES-1026, ES-1027 and ES-1029. ES-1027 is included in the national distribution of the Engineering Field Manual as Exhibit 2-10. Users requiring ES-1026, and/or ES-1029 may obtain same from the SCS Regional Technical Service Center, Portland, Oregon.

Example 2-1

Given an 80-acre watershed in an area using the Type II storm distribution. The Soil Scientist has classified the soils as belonging to Hydrologic soil group B. The average watershed slope is estimated to be between 3 and 8 percent. It is intensively cultivated without conservation treatment. The peak discharge rate from a 25-year frequency storm is desired for the design of a concrete channel at the watershed outlet.

1. Curve number 81 is obtained from Exhibit 2-2 and rounded to 80.

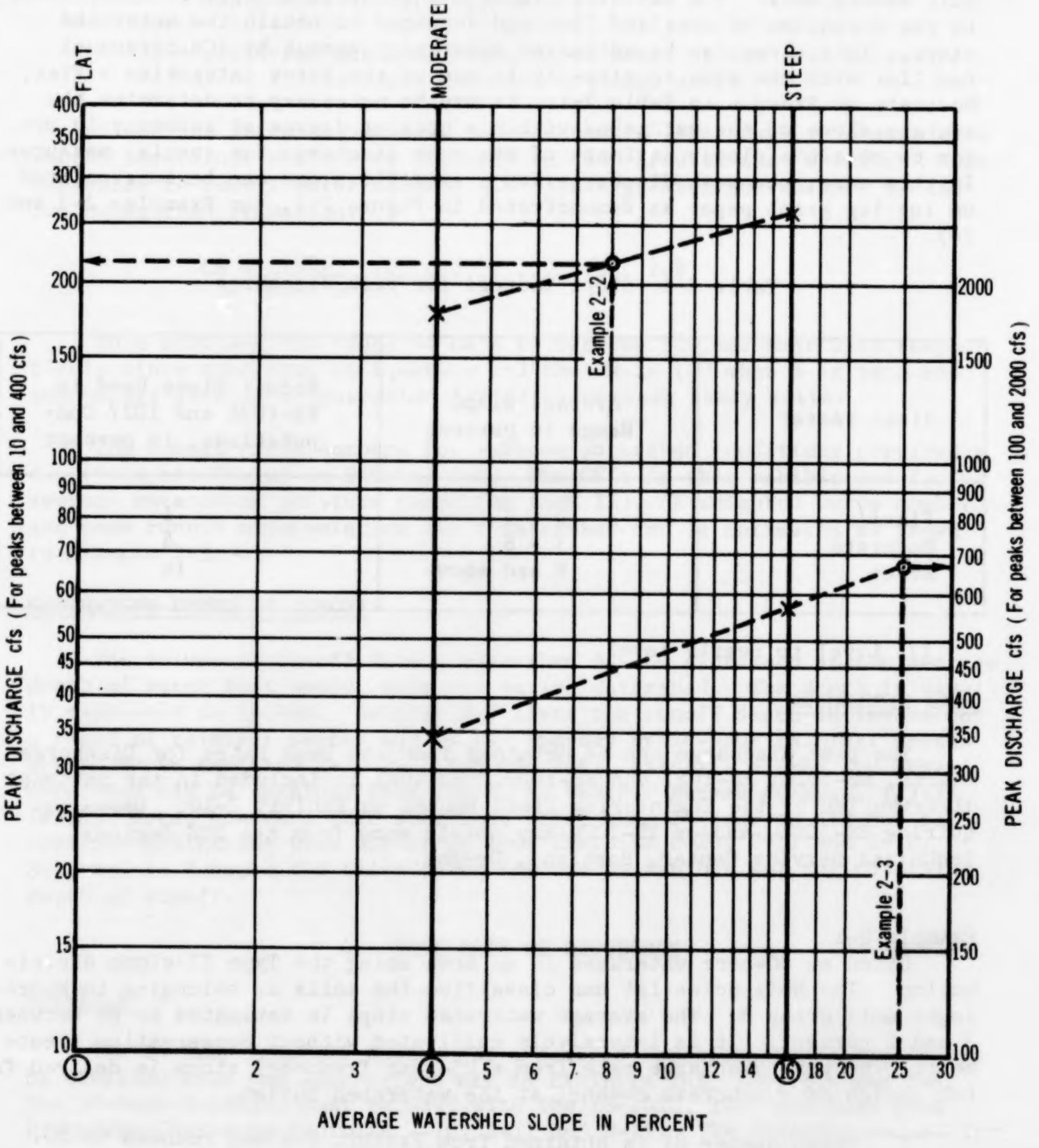

Figure 2-1.--Examples of interpolating peak discharge for average watershed slopes between and greater than Flat, Moderate, and Steep

2. Slope factor is Moderate because of the 3 to 8 percent average watershed slope . See Table 2-1.

3. Storm rainfall for the location of the watershed is obtained from Exhibit 2-3, sheet 4 of 5. For this example, assume the storm rainfall is 8 inches.

4. See Exhibit 2-10, sheet 12 of 21, for Type II, CN-80. Read 315 cfs for the peak runoff from an 8-inch rainfall on the 80 acre watershed.

Example 2-2.

Given a 100-acre watershed in the Type II rainfall area. The soil scientists has classified the soils as belonging mostly in hydrologic soil group C with an average slope of 8 percent. The watershed is in poor pasture. The volume and peak rate of runoff from a 24-hour, 50-year frequency storm is desired for the design of a pipe drop-inlet structure.

1. Curve number 86 is obtained from Exhibit 2-2 and rounded to 85.

2. The 50-year frequency storm rainfall is found in Exhibit 2-3 sheet 5 of 5. Assume a depth of 4 inches.

3. Volume of runoff from Exhibit 2-7 is 2.46 inches for a rainfall of 4 inches and CN 85.

4. From Exhibit 2-10, the peak rate of runoff, CN-85, 100 acre watershed and 4 inch rainfall is read as follows:
   Steep Slope (16%), sheet 20 of 21 $q_p = 264$
   Moderate Slope (4%), sheet 13 of 21 $q_p = 180$

5. Using Figure 2-1, the peak discharge is interpolated to be 220 cfs for an 8% slope.

Example 2-3

Given a 1,000 acre watershed in the Type II storm distribution area. About 600 acres of the watershed is in hydrologic soil group B, within which two-thirds of the area is cultivated with good conservation treatment and the other one-third is in good pasture. The remaining 400 acres of the watershed is in hydrologic soil group C, all of which is well cultivated with good conservation treatment. The average watershed slope is about 25 percent. The peak discharge rate for a 10-year frequency storm is desired for the design of a diversion channel at the outlet.

1. A weighted CN is required:
   2/3 of 600 Ac = 400 ac @ CN 71 and (400/1000) 71 = 28.4
   1/3 of 600 Ac = 200 ac @ CN 61 and (200/1000) 61 = 12.2
   400 ac @ CN 78 and (400/1000) 78 = 31.2
   weighted CN = 71.8
   (Round to 72)

2. The storm rainfall is obtained from Exhibits 2-3, sheet 3 of 5. Assume 4 inches.

3. The peak discharge for a Moderate slope, 1000-acre watershed, 4-inch rainfall and CN 72 is calculated as follows:
   CN 70 (Exhibit 2-10, sheet 10 of 21) = 290 cfs.
   CN 75 (Exhibit 2-10, sheet 11 of 21) = 430 cfs.
   CN 72 = 290 + 2/5(430-290) = 346 cfs (4% slope)

4. The peak discharge for a Steep slope, 1000-acre watershed, 4 inch rainfall and CN 72 is calculated as follows
   CN 70 (Exhibit 2-10, sheet 17 of 21) = 489 cfs.
   CN 75 (Exhibit 2-10, sheet 18 of 21) = 711 cfs.
   CN 72 = 489 + 2/5(711-489) = 578 cfs (16% slope).

5. Using Figure 2-1 the peak discharge is interpolated to be 670 cfs.

5. ESTIMATING SEASONAL YIELD FROM SMALL UNGAGED WATERSHEDS

There is no precise analytical method of determining the amount of runoff that might be expected to occur at least every year or every two years on the average in an ungaged watershed. The same factors affecting runoff on an individual storm basis previously described affect the seasonal yield of runoff, but in a much broader degree. A procedure for approximating the seasonal yield of surface runoff is demonstrated by ES-1014, Exhibit 2-8. The limitations and examples of its application to watershed areas between 10 and 2,000 acres are described and demonstrated. This approximation should not be used for watersheds in which most of the soil is classified under hydrologic soil group A. It will be noted that no direct distinction is made between soils in Exhibit 2-8.

Exhibit 2-8 should not be used for estimating seasonal yields in mountainous and Northern areas where the major volume of runoff is the result of snowmelt.

In some areas a better estimate of average annual yield may be obtained from other sources. Other sources include data correlated with gaged streams and published generalized maps of annual runoff. The graph on the right-hand side of Exhibit 2-8 may be used to estimate volumes of runoff for frequencies other than those available through these sources. The inset Table on sheet 2 of 2, Exhibit 2-8, can be used similarly to estimate seasonal yield from other sources of annual yield data.

AASTAD	B
ABAJO	C
ABBOTT	D
ABBOTTSTOWN	C
ABEGG	B
ABELA	B
ABELL	B
ABERDEEN	D
ABES	D
ABILENE	C
ABINGTON	B
ABIQUA	C
ABO	B
ABRA	C
ABRAHAM	B
ABSAROKEE	C
ABSCOTA	B
ABSHER	D
ACACIO	C
ACADEMY	C
ACADIA	D
ACANA	D
ACEITUNAS	B
ACEL	D
ACKER	B
ACKMEN	B
ACME	C
ACO	B
ACOLITA	B
ACOVE	C
ACTON	B
ACUFF	B
ACWORTH	B
ADA	B
ADAIR	D
ADAMS	A
ADAMSON	B
ADAMSTOWN	
ADAMSVILLE	C
ADATON	D
ADAVEN	D
ADDISON	D
ADDY	C
ADE	A
ADEL	A
ADELAIDE	D
ADELANTO	B
ADELPHIA	C
ADENA	C
ADILLIS	A
ADIRONDACK	
ADKINS	B
ADLER	C
ADOLPH	D
ADRIAN	A/D
AENEAS	B
AETNA	B
AFTON	D
AGAR	B
AGASSIZ	D
AGATE	D
AGAWAM	B
AGENCY	C
AGER	D
AGNER	B
AGNEW	B/C
AGNOS	B
AGUA	B
AGUADILLA	A
AGUA DULCE	C
AGUA FRIA	C
AGUEDA	B
AGUILITA	B
AGUIRRE	D
AGUSTIN	B
AHATONE	D
AHL	C
AHLSTROM	C
AHMEEK	B
AHOLT	D
AHTANUM	C
AHWAHNEE	C
AIBONITO	C
AIKEN	B
AIKMAN	D
AILEY	B
AINAKEA	B
AIRMONT	C
AIROTSA	B
AIRPORT	D
AITS	B
AKAKA	A
AKASKA	B
AKELA	C
ALADDIN	B
ALAE	A
ALAELOA	B
ALAGA	A
ALAKAI	D
ALAMA	C
ALAMANCE	B
ALAMO	D
ALAMOSA	C
ALAPAHA	D
ALAPAI	A
ALBAN	B
ALBANO	D
ALBANY	C
ALBATON	D
ALBEE	C
ALBEMARLE	B
ALBERTVILLE	C
ALBIA	C
ALBION	B
ALBRIGHTS	C
ALCALDE	C
ALCESTER	B
ALCOA	B
ALCONA	B
ALCOVA	B
ALDA	C
ALDAX	D
ALDEN	D
ALDER	B
ALDERDALE	C
ALDERWOOD	C
ALDINO	C
ALEKNAGIK	B
ALEX	B
ALEXANDRIA	C
ALEXIS	B
ALFORD	B
ALGANSEE	B
ALGIERS	C/D
ALGOMA	B/D
ALICE	A
ALICEL	B
ALICIA	C
ALIDA	B
ALIKCHI	B
ALKO	D
ALLAGASH	B
ALLARD	B
ALLEGHENY	B
ALLEMANDS	D
ALLEN	B
ALLENDALE	C
ALLENSVILLE	C
ALLENTINE	D
ALLENWOOD	B
ALLEY	C
ALLIANCE	B
ALLIGATOR	D
ALLIS	D
ALLISON	C
ALLOUEZ	C
ALLOWAY	
ALMAC	B
ALMENA	C
ALMONT	D
ALMY	B
ALOHA	C
ALONSO	B
ALOVAR	C
ALPENA	B
ALPON	B
ALPOWA	B
ALPS	
ALSEA	B
ALSTAD	B
ALSTOWN	B
ALTAMONT	C
ALTAVISTA	C
ALTDORF	D
ALTMAR	B
ALTO	C
ALTOGA	C
ALTON	B
ALTUS	B
ALTVAN	B
ALVIN	B
ALVIRA	C
ALVISO	D
AMADOR	D
AMAGON	D
AMALU	D
AMANA	B
AMARGOSA	D
AMARILLO	B
AMASA	B
AMBERSON	
AMBOY	C
AMBRAW	C
AMECEE	A
AMELIA	B
AMENIA	B
AMERICUS	A
AMES	C
AMHERST	C
AMITY	C
AMMON	B
AMOLE	C
AMOR	B
AMOS	C
AMSTERDAM	B
AMTOFT	D
AMY	D
ANACAPA	B
ANAHUAC	D
ANAMITE	D
ANAPRA	B
ANATONE	D
ANAVERDE	B
ANCHO	C
ANCHORAGE	A
ANCHOR BAY	D
ANCHOR POINT	B
ANCLOTE	D
ANCO	C
ANDERS	C
ANDERSON	B
ANDES	C
ANDORINIA	C
ANDOVER	D
ANDRES	B
ANDREWS	C
ANED	D
ANETH	A
ANGELICA	D
ANGELINA	B/D
ANGIE	C
ANGLE	A
ANGLEN	B
ANGOLA	C
ANGOSTURA	B
ANIAK	D
ANITA	D
ANKENY	A
ANLAUF	C
ANNABELLA	A
ANNANDALE	C
ANNISTON	B
ANOKA	A
ANONES	C
ANSELMO	A
ANSON	B
ANTELOPE SPRINGS	C
ANTERO	C
ANT FLAT	C
ANTHONY	B
ANTIGO	B
ANTILON	B
ANTIOCH	D
ANTLER	C
ANTOINE	C
ANTY	B
ANWAY	B
ANZA	B
APACHE	D
APAKUIE	A
APISHAPA	C
APISON	B
APPIAN	D
APPLEGATE	C
APPLETON	C
APPLING	B
APRON	B
APT	C
APTAKISIC	B
ARABY	
ARADA	B
ARAPIEN	C
ARAVE	D
ARAVETON	B
ARBELA	C
ARBOR	B
ARBUCKLE	B
ARCATA	B
ARCH	B
ARCHABAL	B
ARCHER	C
ARCHIN	C
ARCO	B
ARCOLA	C
ARD	C
ARDEN	B
ARDENVOIR	B
ARDILLA	C
AREDALE	B
ARENA	C
ARENALES	A
ARENDTSVILLE	B
ARENOSA	A
ARENZVILLE	B
ARGONAUT	D
ARGUELLO	B
ARGYLE	B
ARIZO	A
ARKABUTLA	C
ARKPORT	B
ARLAND	B
ARLING	D
ARLINGTON	A
ARLOVAL	C
ARMAGH	D
ARMINGTON	D
ARMO	B
ARMOUR	B
ARMSTER	C
ARMSTRONG	D
ARMUCHEE	D
ARNEGARD	B
ARNHART	C
ARNHEIM	C
ARNO	D
ARNOLD	B
ARNOT	C/D
AROOSTOOK	
AROSA	D
ARP	D
ARRINGTON	B
ARROLIME	C
ARRON	C
ARROW	B
ARROWSMITH	B
ARTA	C
ARTOIS	C
ARVACA	D
ARVANA	C
ARVESON	C
ARVILLA	B
ARZELL	C
ASA	B
ASBURY	
ASCALON	B
ASCHUFF	B
ASCROFT	B
ASHBY	C
ASHDALE	B
ASHE	B
ASHKUM	C
ASHLEY	A
ASH SPRINGS	C
ASHTON	B
ASHUE	B
ASHUELOT	C
ASHWOOD	C
ASKEW	C
ASO	D
ASOTIN	C
ASPEN	B
ASPERMONT	B
ASSINNIBOINE	B
ASSUMPTION	B
ASTATULA	A
ASTOR	A/D
ASTORIA	B
ATASCADERO	C
ATCO	B
ATEPIC	C
ATHELWOLD	B
ATHENA	B
ATHENS	B
ATHERTON	B/D
ATHOL	B
ATKINSON	B
ATLAS	D
ATLEE	C
ATMORE	B/D
ATOKA	C
ATSION	C
ATTERBERRY	B
ATTEWAN	A
ATTICA	B
ATTLEBORO	
ATWATER	B
ATWELL	C
ATWOOD	B
AUBBEENAUBBEE	B
AUBERRY	B
AUBURN	C
AUBURNDALE	D
AUDIAN	B
AU GRES	C
AUGSBURG	B
AUGUSTA	C
AULD	D
AURA	B
AURORA	C
AUSTIN	C
AUXVASSE	D
AUZQUI	B
AVA	C
AVALANCHE	B
AVALON	B
AVERY	B
AVON	C
AVONBURG	D
AVONDALE	B
AWBREY	D
AXTELL	D
AYAR	C
AYCOCK	B
AYR	B
AYRES	D
AYRSHIRE	C
AYSEES	B
AZTALAN	B
AZTEC	B
AZULE	C
AZWELL	B
BABB	A
BABBINGTON	B
BABCOCK	B
BABYLON	A
BACA	C
BACH	D
BACHUS	B
BACKBONE	A
BADENAUGH	B
BADGER	C
BADGERTON	B
BADO	D
BADUS	C
BAGCAD	B
BAGGOTT	D
BAGLEY	B
BAHEM	B
BAILE	D
BAINVILLE	C
BAIRD HOLLOW	C
BAJURA	D
BAKEOVEN	D
BAKER	C
BAKER PASS	B
BALAAM	A
BALCH	D
BALCOM	B
BALD	C
BALDER	C
BALDOCK	B/C
BALDWIN	D
BALOY	B
BALE	C
BALLARD	B
BALLINGER	C
BALM	B/C
BALMAN	B/C
BALON	B
BALTIC	D
BALTIMORE	B
BAMBER	B
BAMFORTH	B
BANCAS	B
BANCROFT	B
BANDERA	B
BANGO	C
BANGOR	B

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January, 1971

EXHIBIT 2-1

BANGSTON	A	BEATTY		BERTELSON	A	BLAKENEY	C	BORDA	D
BANKARD	A	BEAUCOUP	B	BERTHOUD	B	BLAKEPORT	B	BORDEAUX	B
BANKS	A	BEAUFORD	D	BERTIE	C	BLAMER	C	BORDEN	B
BANNER	C	BEAUMONT	D	BERTOLOTTI	B	BLANCA	B	BORDER	B
BANNERVILLE	C/D	BEAUREGARD	C	BERTRAND	B	BLANCHARD	A	BORNSTEDT	B
BANNOCK	B	BEAUSITE	B	BERVILLE	D	BLANCHESTER	B/D	BORREGO	C
BANQUETE	D	BEAVERTON	B	BERYL	B	BLAND	C	BORUP	B
BARABOO	B	BECK	C	BESSEMER	B	BLANDFORD	C	BORVANT	D
BARAGA	C	BECKER	B	BETHANY	C	BLANDING	B	BORZA	C
BARBARY	D	BECKET	C	BETHEL	D	BLANEY	B	BOSANKO	D
BARBOUR	B	BECKLEY	B	BETTERAVIA	C	BLANKET	C	BOSCO	B
BARBOURVILLE	B	BECKTON	D	BETTS	B	BLANTON	A	BOSKET	B
BARCLAY	C	BECKWITH	C	BEULAH	B	BLANYON	C	BOSLER	B
BARCO	B	BECKWOURTH	B	BEVENT	B	BLASINGAME	C	BOSQUE	B
BARCUS	B	BECREEK	B	BEVERLY	B	BLENCOE	C	BOSS	D
BARD	D	BEDFORD	C	BEW	D	BLEND	D	BOSTON	C
BARDEN	C	BEDINGTON	B	BEWLEYVILLE	B	BLENDON	B	BOSTWICK	B
BARDLEY	C	BEDNER	C	BEWLIN	D	BLETHEN	B	BOSWELL	D
BARELA	C	BEEBE	A	BEXAR	C	BLEVINS	B	BOSWORTH	D
BARFIELD	D	BEECHER	C	BEZZANT	B	BLICHTON	D	BOTELLA	B
BARFUSS	B	BEECHY		BIBB	B/D	BLISS	D	BOTHWELL	C
BARKER	C	BEEHIVE	B	BIBON	A	BLOCKTON	C	BOTTINEAU	C
BARKERVILLE	C	BEEZAR	B	BICKELTON	B	BLODGETT	A	BOTTLE	A
BARKLEY	B	BEHANIN	B	BICKMORE	C	BLOMFORD	B	BOULDER	B
BARLANE	D	BEHEMOTOSH	B	BICONDOA	C	BLOOM	C	BOULDER LAKE	D
BARLOW	B	BEJUCOS	B	BIDDEFORD	D	BLOOMFIELD	A	BOULDER POINT	B
BARNARD	D	BELDEN	D	BIDDLEMAN	C	BLOOMING	B	BOULFLAT	D
BARNES	B	BELDING	B	BIDWELL	B	BLOOR	D	BOURNE	C
BARNESTON	B	BELFAST	B	BIEBER	D	BLOSSOM	C	BOW	C
BARNEY	A	BELFIELD	D	BIENVILLE	A	BLOUNT	C	BOWBELLS	B
BARNHARDT	B	BELFORE	B	BIG BLUE	D	BLUCHER	C	BOWDOIN	D
BARNSTEAD		BELGRADE	B	BIGEL	A	BLUEBELL	C	BOWDRE	C
BARNUM	B	BELINDA	D	BIGETTY	C	BLUE EARTH	D	BOWERS	C
BARRADA	D	BELKNAP	C	BIGGS	A	BLUEJOINT	B	BOWIE	B
BARRINGTON	B	BELLAMY	B	BIGGSVILLE	B	BLUE LAKE	A	BOWMAN	B
BARRON	B	BELLAVISTA	D	BIG HORN	C	BLUEPOINT	B	BOWMANSVILLE	C
BARRONETT	C	BELLE	B	BIG TIMBER	D	BLUE STAR	B	BOX ELDER	C
BARROWS	D	BELLEFONTAINE		BIGWIN	A	BLUEWING	B	BOXWELL	C
BARRY	D	BELLICUM	B	BIJOU	A	BLUFFDALE	C	BOY	A
BARSTOW	B	BELLINGHAM	C	BILLETT	A	BLUFFTON	D	BOYCE	B/D
BARTH	C	BELLPINE	C	BILLINGS	C	BLUFORD	D	BOYD	D
BARTLE	D	BELMONT	B	BINFORD	B	BLY	B	BOYER	B
BARTON	B	BELMORE	B	BINGHAM	B	BLYTHE	D	BOYNTON	
BARTONFLAT	B	BELT	D	BINNSVILLE	D	BOARDTREE	C	BOYSAG	D
BARVON	C	BELTED	D	BINS	B	BOBS	D	BOYSEN	B
BASCOM	B	BELTRAMI	B	BIPPUS	B	BOBTAIL	B	BOZARTH	C
BASEHOR	D	BELTSVILLE	C	BIRCH	A	BOCK	B	BOZE	B
BASHAW	D	BELUGA	C	BIRCHWOOD	C	BODENBURG	B	BOZEMAN	A
BASHER	B	BELVOIR	C	BIRDS	C	BODINE	B	BRACEVILLE	C
BASILE	D	BENCLARE	C	BIRDSALL	D	BOEL	A	BRACKEN	D
BASIN	C	BENEVOLA	C	BIRDSBORO	B	BOELUS	A	BRACKETT	C
BASINGER	C	BENEWAH	C	BIRDSLEY	D	BOETTCHER	C	BRAD	D
BASKET	C	BENFIRLD	C	BIRKBECK	B	BOGAN	C	BRADDOCK	C
BASS	A	BENGE	B	BISBEE	A	BOGART	B	BRADENTON	B/D
BASSEL	B	BEN HUR	B	BISCAY	C	BOGUE	D	BRADER	C
BASSETT	B	BENIN	D	BISHOP	B/C	BOHANNON	C	BRADFORD	B
BASSLER	D	BENITO	D	BISPING	B	BOHEMIAN	B	BRADSHAW	A
BASTIAN	D	BENJAMIN	D	BISSELL	B	BOISTFORT	C	BRADWAY	C
BASTROP	B	BEN LOMOND	B	BIT	D	BOLAR	C	BRADY	B
BATAVIA	B	BENMAN	A	BITTERON	A	BOLD	B	BRADYVILLE	C
BATES	B	BENNDALE	B	BITTERROOT	C	BOLES	C	BRAHAM	B
BATH	C	BENNETT	C	BITTER SPRING	C	BOLIVAR	B	BRAINERD	B
BATTLE CREEK	C	BENNINGTON	D	BITTERSPRING	C	BOLIVIA	B	BRALLIER	D
BATZA	C	BENOIT	C	BIXBY	B	BOLTON	B	BRAM	B
BAUDETTE	B	BENSON	C/D	BJORK	C	BOMBAY	B	BRAMARD	B
BAUER	C	BENTONVILLE		BLACHLY	C	BON	B	BRAMBLE	C
BAUGH	B/C	BENZ	D	BLACK BUTTE	C	BONACCORD	C	BRAMWELL	D
BAXTER	B	BEOTIA	B	BLACK CANYON	D	BONAPARTE	A	BRAND	D
BAXTERVILLE	B	BEOWAWE	C	BLACKCAP	A	BOND	C	BRANDENBURG	A
BAYAMON	B	BERCAIL	C	BLACKETT	B	BONDRANCH	D	BRANDON	B
BAYARD	A	BERDA	B	BLACKFOOT	B	BONDURANT	B	BRANDYWINE	C
BAYBORO	D	BEREA	C	BLACKHALL	D	BONE	D	BRANFORD	B
BAYSHORE	B/C	BERENICETON	B	BLACKHAWK	D	BONG	B	BRANTFORD	B
BAYSIDE	C	BERENT	A	BLACKLEAF	B	BONHAM	C	BRASHEAR	C
BAYWOOD	A	BERGLAND	D	BLACKLOCK	D	BONILLA	B	BRASSFIELD	B
BAZETTE	C	BERGSTROM	B	BLACKMAN	C	BONITA	D	BRATTON	B
BEAD	C	BERINO	B	BLACK MOUNTAIN	B	BONN	D	BRAXTON	C
BEADLE	C	BERKELEY		BLACKOAR	C	BONNER	B	BRAYMILL	B/D
BEALES	A	BERKS	C	BLACKPIPE	C	BONNET	B	BRAYS	D
BEAR BASIN	B	BERKSHIRE	B	BLACK RIDGE	C	BONNEVILLE	B	BRAYTON	C
BEAR CREEK	C	BERLIN	C	BLACKROCK	B	BONNICK	A	BRAZITO	A
BEARDALL	C	BERMUDIAN	B	BLACKSTON	B	BONNIE	D	BRAZOS	A
BEARDEN	C	BERNAL	C	BLACKTAIL	B	BONO	D	BRECKENRIDGE	D
BEARDSTOWN	C	BERNALDO	B	BLACKWATER	D	BONSALL	D	BRECKNOCK	B
BEAR LAKE	D	BERNARD	D	BLACKWELL	B/D	BONTA	C	BREECE	B
BEARMOUTH	A	BERNARDINO	C	BLADEN	D	BONTI	C	BREGAR	D
BEARPAW	B	BERNARDSTON	C	BLAGO	D	BOOKER	D	BREPEN	B
BEAR PRAIRIE	B	BERNHILL	B	BLAINE	B	BOOMER	B	BREPER	B
BEARSKIN	D	BERNICE	A	BLAIR	C	BOONE	A	BREMO	C
BEASLEY	C	BERNING	C	BLAIRTON	C	BOONESBORO	B	BREMS	A
BEASON	C	BERRENDOS	D	BLAKE	C	BOOTH	C	BRENDA	C
BEATON	C	BERRYLAND	D	BLAKELAND	A	BORAH	A	BRENNAN	B

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EXHIBIT 2-1

BRENNER	C/D	BUCKLEY	B/C	CAID	B	CAPUTA	C	CATLIN	B
BRENT	C	BUCKLON	D	CAIRO	D	CARACO	C	CATNIP	D
BRENTON	B	BUCKNER	A	CAJALCO	C	CARALAMPI	B	CATOCTIN	C
BRENTWOOD	B	BUCKNEY	A	CAJON	A	CARBO	C	CATOOSA	B
BRESSER	B	BUCKS	B	CALABAR	D	CARBOL	D	CATSKILL	A
BREVARD	B	BUCKSKIN	C	CALABASAS	C	CARBONDALE	D	CATTARAUGUS	C
BREVORT	B	BUCODA	C	CALAIS	C	CARBURY	B	CAUDLE	B
BREWER	C	BUDD	B	CALAMINE	D	CARDIFF	B	CAVE	D
BREWSTER	D	BUDE	C	CALAPOOYA	C	CARDINGTON	C	CAVE ROCK	A
BREWTON	C	BUDE	C	CALAWAH	B	CARDON	D	CAVO	D
BRICKEL	C	BUELL	A	CALCO	C	CAREY	B	CAVODE	C
BRICKTON	C	BUENA VISTA	B	CALDER	D	CAREY LAKE	B	CAVOUR	D
BRIDGE	C	BUFFINGTON	B	CALDWELL	B	CAREYTOWN	D	CAWKER	B
BRIDGEHAMPTON	B	BUFF PEAK	C	CALEAST	C	CARGILL	C	CAYAGUA	C
BRIDGEPORT	B	BUICK	C	CALEB	B	CARIBE	B	CAYLOR	B
BRIDGER	A	BUKREEK	B	CALERA	C	CARIBEL	B	CAYUGA	C
BRIDGESON	B/C	BULLION	D	CALHI	A	CARIBOU	B	CAZADERO	C
BRIDGEVILLE	B	BULLREY	B	CALHOUN	D	CARLIN	D	CAZADOR	B
BRIDGPORT	B	BULL RUN	B	CALICO	D	CARLINTON	B	CAZENOVIA	B
BRIEDWELL	B	BULL TRAIL	B	CALIFON	C	CARLISLE	A/D	CEBOLIA	C
BRIEF	B	BULLY	B	CALIMUS	B	CARLOTTA	B	CECIL	B
BRIENSBURG		BUMGARD	B	CALITA	B	CARLOW	D	CEDARAN	D
BRIGGS	A	BUNCOMBE	A	CALIZA	A	CARLSBAD	C	CEDAR BUTTE	C
BRIGGSDALE	C	BUNDO	B	CALKINS	C	CARLSBORG	A	CEDAREDGE	B
BRIGGSVILLE	C	BUNEJUG	C	CALLAHAN	C	CARLSON	C	CEDAR MT.	D
BRIGHTON	A/D	BUNKER	D	CALLEGUAS	D	CARLTON	B	CEDARVILLE	B
BRIGHTWOOD	C	BUNSELMEIER	C	CALLINGS	C	CARMI	B	CEDONIA	B
BRILL	B	BUNTINGVILLE	B/C	CALLOWAY	C	CARNEGIE	C	CEDRON	C/D
BRIM	C	BUNYAN	B	CALMAR	B	CARNERO	C	CELAYA	B
BRIMFIELD	C/D	BURBANK	A	CALNEVA	C	CARNEY	D	CELETON	D
BRIMLEY	B	BURCH	B	CALOUSE	B	CAROLINE	C	CELINA	C
BRINEGAR	B	BURCHARD	B	CALPINE	B	CARR	B	CELIO	A
BRINKERTON	D	BURCHELL	B/C	CALVERT	D	CARRISALITOS	D	CELLAR	D
BRISCOT	B	BURDETT	C	CALVERTON	C	CARRIZO	A	CENCOVE	B
BRITE	C	BUREN	C	CALVIN	C	CARSO	D	CENTER	C
BRITTON	C	BURGESS	B	CALVISTA	D	CARSON	D	CENTER CREEK	B
BRIZAM	A	BURGI	B	CAM	B	CARSTAIRS	B	CENTERFIELD	B
BROAD	C	BURGIN	D	CAMAGUEY	D	CARSTUMP	C	CENTERVILLE	D
BROADALBIN	C	BURKE	C	CAMARGO	B	CARTAGENA	D	CENTRALIA	B
BROADAX	B	BURKHARDT	B	CAMARILLO	B/C	CARTECAY	C	CENTRAL POINT	B
BROADBROOK	C	BURLEIGH	D	CAMAS	A	CARUSO	C	CERESCO	A
BROAD CANYON	B	BURLESON	D	CAMASCREEK	B/D	CARUTHERSVILLE	B	CERRILLOS	C
BROADHEAD	C	BURLINGTON	A	CAMBERN	C	CARVER	A	CERRO	C
BROADHURST	D	BURMA		CAMBRIDGE	C	CARWILE	D	CHACRA	C
BROCK	D	BURMESTER	D	CAMDEN	B	CARYVILLE	B	CHAFFEE	C
BROCKLISS	C	BURNAC	C	CAMERON	D	CASA GRANDE	C	CHAGRIN	B
BROCKMAN	C	BURNETTE	B	CAMILLUS	B	CASCADE	C	CHAIX	B
BROCKPORT	D	BURNHAM	D	CAMP	B	CASCAJO	B	CHALFONT	C
BROCKTON	D	BURNSIDE	B	CAMPBELL	B/C	CASCILLA	B	CHALMERS	C
BROCKWAY	B	BURNSVILLE	B	CAMPHORA	B	CASCO	B	CHAMA	B
BRODY	C	BURNT LAKE	B	CAMPIA	B	CASE	B	CHAMBER	C
BROGAN	B	BURRIS	D	CAMPO	C	CASEBIER	D	CHAMBERINO	C
BROGDON	B	BURT	D	CAMPONE	B/C	CASEY	C	CHAMISE	B
BROLLIAR	D	BURTON	B	CAMPSPASS	C	CASHEL	C	CHAMOKANE	B
BROMO	B	BUSE	B	CAMPUS	B	CASHION	D	CHAMPION	B
BRONAUGH	B	BUSHNELL	C	CAMRODEN	C	CASHMERE	B	CHANCE	B/D
BRONCHO	B	BUSHVALLEY	D	CANA	C	CASHMONT	B	CHANDLER	B
BRONSON	B	BUSTER	C	CANAAN	C/D	CASINO	A	CHANEY	C
BRONTE	C	BUTANO	C	CANADIAN	B	CASITO	C	CHANNAHON	B
BROOKE	C	BUTLER	D	CANADICE	D	CASPAR	B	CHANNING	B
BROOKFIELD	B	BUTLERTOWN	C	CANANDAIGUA	D	CASPIANA	B	CHANTA	B
BROOKINGS	B	BUTTE	C	CANASERAGA	C	CASS	A	CHANTIER	D
BROOKLYN	D	BUTTERFIELD	C	CANAVERAL	C	CASSADAGA		CHAPIN	C
BROOKSIDE	C	BUXIN	D	CANDELERO	C	CASSIA	C	CHAPMAN	
BROOKSTON	B/D	BUXTON	C	CANE	C	CASSCLARY	B	CHAPPELL	B
BROOKSVILLE	D	BYARS	D	CANEADEA	D	CASSVILLE		CHARD	B
BROSELEY	B	BYRON	A	CANEEK	B	CASTAIC	C	CHARITON	D
BROSS	B			CANEL	B	CASTALIA	C	CHARITY	D
BROUGHTON	D	CABALLO	C	CANELOX	C	CASTANA	B	CHARLESTON	C
BROWARD	C	CABARTON	C	CANEY	C	CASTELL	C	CHARLEVOIX	B
BROWNELL	B	CABBA	C	CANEYVILLE	C	CASTILE	B	CHARLOS	A
BROWNFIELD	A	CABBART	D	CANFIELD	C	CASTINE	C	CHARLOTTE	A/D
BROWNLEE	B	CABEZON	D	CANISTEO	C	CASTLE	D	CHARLTON	B
BROYLES	C	CABIN	C	CANNINGER	B	CASTLE VALLEY	D	CHASE	C
BRUCE	D	CABINET	C	CANOE	B	CASTNER	C	CHASEBURG	B
BRUIN	C	CABLE	D	CANONCITO	C	CASTO	C	CHASEVILLE	A
BRUNEEL	B	CABO ROJO	C	CANOVA	B/D	CASTRO	C	CHASKA	C
BRUNO	A	CABOT	D	CANTON	B	CASTROVILLE	B	CHASTAIN	D
BRUNT	C	CACAPON	B	CANTRIL	B	CASUSE	D	CHATBURN	B
BRUSETT	B	CACHE	D	CANTUA	B	CASWELL	B	CHATFIELD	
BRUSH		CACIQUE	B	CANUTIO	B	CATALINA	B	CHATHAM	B
BRUSSETT	B	CADDO	D	CANYON	D	CATALPA	C	CHATSWORTH	D
BRYAN	A	CADEVILLE	D	CAPAC	B	CATANO	A	CHAUNCEY	C
BRYCAN	B	CADMUS	B	CAPAY	D	CATARINA	D	CHAVIES	B
BRYCE	D	CADOMA	C	CAPE	D	CATAULA	C	CHAWANAKEE	C
BUCAN	D	CADON	C	CAPE FEAR	D	CATAWBA	B	CHEADLE	C
BUCHANAN	C	CAGEY	C	CAPERS	D	CATH	D	CHECKETT	D
BUCHENAU	C	CAGUABO	D	CAPILLO	D	CATHCART	B	CHEDAHAP	B
BUCHER	C	CAHABA	B	CAPLES	C	CATHEDRAL	C	CHEEKTOWAGA	D
BUCKINGHAM		CAHILL	B	CAPPS	B	CATHERINE	B/D	CHEESMAN	B
BUCKLAND	C	CAHONE	C	CAPSHAW	C	CATHRO	D	CHEHALEM	C
BUCKLEBAR	B	CAHTO	C	CAPULIN	C	CATLETT	C/D	CHEHALIS	B

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CHEMULPUM	C	CHUTE	A	COACHELLA	B	CONALB	B	COTITO	C
CHELAN	B	CIALES	D	COAD	B	CONANT	C	COTO	C
CHELSEA	A	CIALITOS	B	COAL CREEK	C	CONASAUGA	C	COTOPAXI	A
CHEMAWA	B	CIBEQUE	B	COALMONT	C	CONATA	D	COTT	B
CHEMUNG		CIBO	D	COAMO	C	CONBOY	D	COTTER	B
CHEN	D	CIBOLA	B	COARSEGOLD	B	CONCHAS	C	COTTERAL	B
CHENA	A	CICERO	D	COATICOOK	C	CONCHO	C	COTTIER	B
CHENANGO	A	CIDERCONE	B	COATSBURG	D	CONCONULLY	B	COTTONWOOD	C
CHENEY	B	CIORAL	C	COBB	B	CONCORD	D	COTTRELL	C
CHENNEBY	C	CIENEBA	B	COBEN	D	CONCREEK	B	COUCH	C
CHENOWETH	B	CIMA	C	COBEY	B	CONDA	C	COUGAR	C
CHEQUEST	C	CIMARRON	C	COBURG	C	CONDIT	D	COULSTONE	B
CHEREETE	A	CINCINNATI	C	COCHETOPA	C	CONDON	C	COUNTS	C
CHEROKEE	D	CINCO	A	COCOA	A	CONE	A	COUPEVILLE	B
CHERRY	C	CINEBAR	B	COCOLALLA	C	CONEJO	C	COURT	B
CHERRYHILL	C	CIRCLE	C	CODORUS	C	CONESTOGA	B	COURTHOUSE	D
CHERRY SPRINGS	D	CIRCLEVILLE	C	CODY	A	CONESUS	B	COURTLAND	B
CHESAW	B	CISNE	D	COE	A	CONGAREE	B	COURTNEY	D
CHESHIRE	B	CISPUS	A	COEBURN	C	CONI	D	COURTROCK	B
CHESHNINA	D	CITICO	B	COFF	D	CONLEN	B	COUSE	C
CHESNIMNUS	B	CLACKAMAS	C	COGGON	B	CONLEY	C	COUSHATTA	B
CHESTER	B	CLAIBORNE	B	COGSWELL	C	CONNEAUT	C	COVE	D
CHESTERTON	C	CLAIRE	A	COHASSET	B	CONNECTICUT		COVELLO	B
CHETCO	D	CLAIREMONT	B	COHOCTAH	D	CONNER	B	COVELAND	C
CHETEK	B	CLALLAM	B	COHOE	B	CONOTTON	B	COVENTRY	B
CHEVELON	C	CLAM GULCH	C	COIT	C	CONOVER	B	COVEYTOWN	C
CHEWACLA	C	CLAMO	C	COKEDALE	C	CONOWINGO	C	COVINGTON	D
CHEWELAH	B	CLANTON	C	COKEL	C	CONRAD	B	COWAN	A
CHEYENNE	B	CLAPPER	B	COKER	D	CONROE	B	COWARTS	C
CHIARA	D	CLAREMORE	D	COKESBURY	D	CONSER	C/D	COWDEN	D
CHICKASHA	B	CLARENCE	D	COKEVILLE	B	CONSTABLE	A	COWDRY	C
CHICOPEE	B	CLARESON	C	COLBATH	C/D	CONSUMO	B	COWEEMAN	C
CHICOTE	D	CLAREVILLE	C	COLBERT	D	CONTINENTAL	C	COWERS	B
CHIGLEY	C	CLARINDA	D	COLBURN	B	CONTRA COSTA	C	COWICHE	B
CHIECOTT	D	CLARION	B	COLBY	B	CONVENT	C	COWOOD	C
CHILDS	B	CLARITA	D	COLCHESTER	B	COOK	D	COX	D
CHILGREN	C	CLARK	B	COLDEN		COOKPORT	C	COXVILLE	D
CHILHOWIE	C	CLARK FORK	A	COLD SPRINGS	C	COOLBRITH	B	COYATA	C
CHILI	B	CLARKSBURG	C	COLE	B/C	COOLVILLE	C	COZAD	B
CHILLICOTHE	C	CLARKSDALE	C	COLEBROOK	B	COOMBS	B	CRABTON	B
CHILLISQUAQUE		CLARKSON	B	COLEMAN	C	COONEY	B	CRADDOCK	B
CHILLUM	B	CLARKSVILLE	B	COLEMANTOWN	D	COOPER	C	CRADLEBAUGH	D
CHILMARK	B	CLARNO	B	COLETO	A	COOTER	C	CRAFTON	C
CHILO	B/D	CLARY	B	COLFAX	C	COPAKE	B	CRAGO	B
CHILOQUIN	B	CLATO	B	COLINAS	B	COPALIS	B	CRAIG	C
CHILSON	D	CLATSOP	D	COLLAMER	C	COPELAND	B/D	CRAIGMONT	C
CHILTON	B	CLAVERACK	C	COLLARD	B	COPITA	B	CRAPER	D
CHIMAYO	C	CLAWSON	C	COLLBRAN	C	COPLAY		CRANE	B
CHIMNEY	B	CLAYBURN	B	COLLEEN	C	COPPER RIVER	D	CRANSTON	B
CHINA CREEK	B	CLAYSPRINGS	D	COLLEGIATE	C	COPPERTON	B	CRARY	C
CHINCHALLO	B/D	CLAYTON	B	COLLETT	C	COPPOCK	B	CRATER LAKE	B
CHINIAK	A	CLEARFIELD	C	COLLIER	A	COPSEY	D	CRAVEN	C
CHINO	B/C	CLEAR LAKE	D	COLLINGTON	B	COQUILLE	C/D	CRAWFORD	D
CHINOOK	B	CLEEK	C	COLLINS	C	CORA	D	CREAL	D
CHIPETA	D	CLE ELUM	B	COLLINSTON	C	CORAL	C	CREBBIN	C
CHIPLEY	C	CLEGG	B	COLLINSVILLE	C	CORBETT	C	CREEDMAN	D
CHIPMAN	C	CLEMAN	B	COLMA	B	CORBIN	B	CREEDMOOR	C
CHIPPENY	D	CLEMVILLE	B	COLMOR	C	CORCEGA	C	CREIGHTON	B
CHIPPEWA	B/D	CLEORA	B	COLO	B	CORD	C	CRELDON	B
CHIQUITO	C	CLERF	B	COLOCKUM	B	CORDES	B	CRESBARD	C
CHIRICAHUA	D	CLERMONT	D	COLOMA	A	CORDOVA	C	CRESCENT	B
CHITINA	B	CLEVERLY	A	COLOMBO	B	CORINTH	C	CRESCO	C
CHITTENDEN	C	CLIFFDOWN	C	COLONA	C	CORKINDALE	B	CREST	C
CHITWOOD	C	CLIFFHOUSE	C	COLONIE	A	CORLENA	A	CRESTLINE	B
CHIVATO	D	CLIFFORD	B	COLORADO	B	CORLETT	B	CRESTMORE	
CHIWAWA	B	CLIFFWOOD	C	COLOROCK	D	CORLEY	C	CRESTON	A
CHO	C	CLIFTERSON	B	COLOSO	D	CORMANT	C	CRESWELL	C
CHOBEE	D	CLIFTON	C	COLOSSE	A	CORNHILL	B	CRETE	D
CHOCK	B/D	CLIFTY	B	COLP	D	CORNING	D	CREVA	D
CHOCOLOCCO	B	CLIMARA	D	COLRAIN	B	CORNUTT	C	CREVASSE	A
CHOPAKA	C	CLIMAX	C	COLTON	A	CORNVILLE	B	CREWS	D
CHOPTANK	A	CLIME	C	COLTS NECK	B	COROZAL	C	CRIDER	B
CHOPTIE	D	CLINTON	B	COLUMBIA	B	CORPENING	D	CRIP	B
CHORALMONT	B	CLODINE	D	COLUMBINE	A	CORRALITOS	A	CRISFIELD	B
CHOTEAU	C	CLONTARF	B	COLUSA	C	CORRECO	C	CRITCHELL	B
CHRISTIAN	C	CLOQUALLUM	C	COLVILLE	B	CORRERA	D	CRIVITZ	A
CHRISTIANA	B	CLOQUATO	B	COLVIN	C	CORSON	C	CROCKER	A
CHRISTIANBURG	D	CLOQUET	B	COLWOOD	B/D	CORTEZ	D	CROCKETT	D
CHRISTY	B	CLOUD	D	COLYER	C/D	CORTINA	A	CROFTON	B
CHROME	C	CLOUDCROFT	D	COMERIO	B	CORUNNA	D	CROGHAN	B
CHUALAR	B	CLOUD PEAK	B	COMETA	C	CORVALLIS	B	CROOKED	C
CHUBBS	C	CLOUD RIM	B	COMFREY	C	CORWIN	B	CROOKED CREEK	D
CHUCKAWALLA	B	CLOUGH	D	COMITAS	A	CORY	C	CROOKSTON	B
CHULITNA	B	CLOVERDALE	D	COMLY	C	CORYDON	C	CROOM	B
CHUMMY	C	CLOVER SPRINGS	B	COMMERCE	C	COSAD	C	CROPLEY	C
CHUMSTICK	C	CLOVIS	B	COMO	A	COSH	C	CROSBY	C
CHUPADERA	B	CLUFF	C	COMODORE	B	COSHOCTON		CROSS	D
CHURCH	D	CLUNIE	D	COMORO	B	COSKI	B	CROSSVILLE	B
CHURCHILL	D	CLURD	C	COMPTCHE	B	COSSAYUNA	C	CROSWELL	A
CHURCHVILLE	D	CLURO	C	COMPTON	C	COSTILLA	A	CROT	D
CHURN	B	CLYDE	D	COMSTOCK	C	COTACO	C	CROTON	D
CHURNDASHER	B	CLYMER	B	COMUS	B	COTATI	C	CROUCH	B

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CROW	C	DANZ	B	DEL REY	C	DIXMONT	C	DRY CREEK	C
CROW CREEK	B	DARGOL	D	DEL RIO	C	DIXMORE	B	DRYDEN	B
CROWFOOT	C	DARIEN	C	DELTA	C	DIXONVILLE	C	DRY LAKE	C
CROWHEART	B	DARLING	B	DELTON	B	DIXVILLE	A	DUANE	B
CROW HILL	C	DARNELL	C	DELWIN	A	DOAK	C	DUBAKELLA	C
CROWLEY	D	DARNEN	B	DELYNDIA	B	DOBBS	B	DUBAY	D
CROWN	B	DARR	A	DEMAST	B	DOBY	D	DUBBS	B
CROWSHAW	B	DARRET	C	DEMASTERS	B	DOCAS	B	DUBOIS	C
CROZIER	C	DARROCH	C	DE MAYA	C	DOCKERY	C	DUBUQUE	B
CRUCKTON	B	DART	A	DEMERS	D	DOCT	B	DUCEY	B
CRUICKSHANK	C	DARVADA	D	DEMKY	D	DODGE	B	DUCHESNE	A
CRUME	B	DARWIN	D	DEMONA	C	DODGEVILLE	B	DUCKETT	C
CRUMP	D	DASSEL	D	DEMOPOLIS	C	DODSON	C	DUCOR	D
CRUTCH	B	DATEMAN	C	DEMPSTER	B	DOGER	A	DUDA	A
CRUTCHER	D	DATINO	C	DENAY	B	DOGUE	C	DUDLEY	D
CRUZE	C	DATWYLER	C	DENISON	C	DOLAND	B	DUEL	B
CRYSTAL LAKE	B	DAULTON	D	DENMARK	D	DOLE	C	DUELM	C
CRYSTAL SPRINGS	D	DAUPHIN		DENNIS	C	DOLLAR	B	DUFFAU	B
CRYSTOLA	B	DAVEY	A	DENNY	D	DOLLARD	C	DUFFER	D
CUBA	B	DAVIDSON	B	DENROCK	D	DOLORES	B	DUFFIELD	B
CUBERANT	B	DAVIS	B	DENTON	D	DOLPH	C	DUFFSON	B
CUCHILLAS	D	DAVISON	B	DENVER	C	DOMINGO	C	DUFFY	B
CUDAHY	D	DAWES	C	DEPEW	C	DOMINGUEZ	C	DUFUR	B
CUDIYO	B	DAWHOO	B/D	DEPOE	D	DOMINIC	A	DUGGINS	D
CUERO	B	DAWSON	D	DERINDA	C	DOMINO	C	DUGOUT	D
CUEVA	D	DAY	D	DESAN	A	DONA ANA	B	DUGWAY	D
CUEVITAS	D	DAYBELL	A	DESART	C	DONALD	B	DUKES	A
CULLEN	C	DAYTON	D	DESCALABRADO	D	DONEGAL		DULAC	C
CULLEOKA	B	DAYVILLE	B/C	DESCHUTES	C	DONERAIL	C	DUMAS	B
CULLO	C	DAZE	D	DESERET	C	DONICA	A	DUMECQ	C
CULPEPER	C	DEACON	B	DESHA	D	DONLONTON	C	DUMONT	C
CULVERS	C	DEADFALL	B	DESHLER	C	DONNA	D	DUNBAR	D
CUMBERLAND	B	DEAMA	C	DESOLATION	C	DONNAN	C	DUNBARTON	C
CUMLEY	C	DEAN	B	DESPAIN	B	DONNYBROOK	D	DUNBRIDGE	B
CUMMINGS	B/D	DEAN LAKE	C	DETER	C	DONOVAN	B	DUNCAN	D
CUNICO	C	DEARDURFF	B	DETLOR	C	DOOLEY	A	DUNCANNON	B
CUPPER	B	DEARY	C	DETOUR	C	DOONE	B	DUNCOM	D
CUROLI	C	DEARYTON	B	DETROIT	C	DOOR	B	DUNDAS	C
CURECANTI	B	DEATMAN	C	DEV	B	DORA	D	DUNDAY	A
CURLEW	C	DEAVER	C	DEVILS DIVE	D	DORAN	C	DUNDEE	C
CURRAN	C	DEBENGER	C	DEVOL	B	DORCHESTER	B	DUNELLEN	B
CURRANT	B	DECAN	D	DEVON	B	DOROSHIN	D	DUNE SAND	A
CURTIS CREEK	D	DECATHON	D	DEVORE	B	DOROTHEA	C	DUNGENESS	B
CURTIS SIDING	A	DECATUR	B	DEWART		DOROVAN	D	DUN GLEN	C
CUSHING	B	DECCA	B	DEWEY	B	DORS	B	DUNKINSVILLE	B
CUSHMAN	C	DECKER	C	DEWVILLE	B	DORSET	B	DUNKIRK	B
CUSTER	C	DECKERVILLE	C	DEXTER	B	DOS CABEZAS	C	DUNLAP	B
CUTTER	D	DECLO	B	DIA	C	DOSSMAN	B	DUNMORE	B
CUTZ	D	DECORRA	B	DIABLO	D	DOTHAN	B	DUNNING	D
CUYAMA	B	DECROSS	B	DIAMOND	C	DOTTA	B	DUNPHY	D
CYLINDER	B	DEE	C	DIAMOND SPRINGS	C	DOTY	B	DUNVILLE	B
CYNTHIANA	C/D	DEEPWATER	C	DIAZ	C	DOUBLETOP	B	DU PAGE	B
CYPREMORT	C	DEER CREEK	C	DIBBLE	C	DOUDS	B	DUPEE	C
CYRIL	B	DEERFIELD	B	DICK	A	DOUGHERTY	A	DUPLIN	C
		DEERFORD	D	DICKEY	A	DOUGHTY	A	DUPO	C
DABOB	B	DEERING	C	DICKINSON	A	DOUGLAS	B	DUPONT	D
DACONA	C	DEERLODGE	D	DICKSON	C	DOURO	B	DUPREE	D
DADE	A	DEER PARK	A	DIGBY	C	DOVER	B	DURALDE	C
DAFTER	B	DEERTON	B	DIGGER	C	DOVRAY	D	DURAND	B
DAGGETT	A	DEERTRAIL	C	DIGHTON	B	DOW	B	DURANT	D
DAGLUM	D	DEFIANCE	D	DILL	B	DOWAGIAC	B	DURELLE	B
DAGOR	B	DEFORD	D	DILLARD	C	DOWDEN	C	DURHAM	B
DAGUAO	C	DEGARMO	B/C	DILLDOWN		DOWELLTON	D	DURKEE	C
DAGUEY	C	DEGNER	C	DILLINGER	B	DOWNER	B	DUROC	B
DAHLQUIST	B	DE GREY	D	DILLON	D	DOWNEY	B	DURRSTEIN	D
DAIGLE	C	DEJARNET	B	DILLWYN	A	DOWNS	B	DUTCHESS	B
DAILEY	A	DEKALB	C	DILMAN	C	DOXIE	C	DUTSON	D
DAKOTA	B	DEKOVEN	D	DILTS	D	DOYCE	C	DUTTON	D
DALBO	B	DELAKE	B	DILWORTH	D	DOYLE	A	DUVAL	B
DALBY	D	DELANCO	C	DIMAL	C	DOYLE	A	DUZEL	B
DALE	B	DELANEY	A	DIMYAW	C	DOYLESTOWN	D	DWIGHT	D
DALHART	B	DELANO	B	DINGLE	B	DOYN	C	DWYER	A
DALIAN	B	DELECO	C	DINGLISHNA	C	DRA	C	DYE	D
DALLAM	B	DELENA	D	DINKELMAN	B	DRACUT	C	DYER	
DALTON	C	DELFINA	B	DINKEY	A	DRAGE	B	DYKE	B
DALUPE	B	DELHI	A	DINNEN	B	DRAGOON	B	DYRENG	D
DAMASCUS	D	DELICIAS	B	DINSDALE	B	DRAGSTON	C		
DAMON	D	DELKS	B/D	DINUBA	B/C	DRAIN	C	EAD	C
DANA	B	DELL	C	DINZER	B	DRAKE	B	EAGAR	B
DANBURY	C	DELLEKER	B	DIOXICE	C	DRANYON	B	EAGLECONE	B
DANBY		DELLO	A/C	DIQUE	B	DRAPER	C	EAKIN	B
DANDREA	C	DELLROSE	B	DISAMEL	D	DRESDEN	B	EAMES	B
DANGRIDGE	D	DELM	D	DISAUTEL	B	DRESSLER	C	EARLE	D
DANGBERG	D	DELMAR	D	DISCO	B	DREWS	B	EARLMONT	B/C
DANIELS	B	DELMITA	C	DISHNER	D	DRIFTON	C	EARP	B
DANKO	D	DELMONT	A	DISTERHEFF	D	DRIGGS	B	EASLEY	D
DANLEY	C	DELNORTE	C	DITCHCAMP	C	DRUM	C	EAST FORK	C
DANNEMORA	D	DELPHI	B	DIVERS	B	DRUMMER	B	EAST LAKE	A
DANSKIN	B	DELPHILL	C	DIVIDE	B	DRUMMOND	D	EASTLAND	C
DANT	D	DELPIEDRA	C	DIX	A	DRURY	B	EASTON	C
DANVERS	C	DELPINE	D	DIX	A	DRYAD	C	EASTONVILLE	A
DANVILLE	C	DELRAY	A/D	DIXIE	C	DRYBURG	B	EAST PARK	D

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EXHIBIT 2-1 January, 1971

EASTPURT	A	ELLISON	B	ESMOND	B	FARNUM	B	FLEISCHMANN	D
EATONTOWN		ELLOAM	D	ESPARTO	B	FARRAGUT	C	FLEMING	C
EAUGALLIE	B/D	ELLSBERRY		ESPIL	D	FARRAR	B	FLETCHER	B
EBA	C	ELLSWORTH	C	ESPINAL	A	FARRELL	B	FLOKE	D
EBBERT	D	ELMA	B	ESQUATZEL	B	FARRENBURG	B	FLOM	C
EBBS	B	ELMDALE	B	ESS	B	FARROT	C	FLOMATION	A
EBENEZER	C	ELMIRA	A	ESSEN	C	FARSON	B	FLORENCE	C
ECCLES	B	ELMO	C	ESSEX	C	FARWELL	C	FLORIDANA	B/D
ECHARD	C	ELMONT	B	ESSEXVILLE	D	FATIMA	B	FLORISSANT	C
ECHLER	B	ELMORE	B	ESTACADO	B	FATTIG	C	FLOWELL	C
ECKLEY	B	ELMWOOD	C	ESTELLINE	B	FAUNCE	A	FLOWEREE	B
ECKMAN	B	ELNORA	B	ESTER	D	FAUQUIER	C	FLOYD	B
ECKRANT	D	ELOIKA	B	ESTERBROOK	B	FAWCETT	C	FLUSHING	
ECTON	C	ELPAN	D	ESTHERVILLE	B	FAWN	B	FLUVANNA	C
EDALGO	C	EL PECO	C	ESTO	C	FAXON	D	FLYGARE	B
EDDS	B	EL RANCHO	B	ESTRELLA	B	FAYAL	C	FLYNN	D
EDDY	C	ELRED	B/D	ETHAN	B	FAYETTE	B	FOARD	D
EDEN	C	ELRED	B/D	ETHETE	B	FAYETTEVILLE	B	FOGELSVILLE	B
EDENTON	C	ELS	A	ETHRIDGE	C	FAYWOOD	C	FOLA	B
EDENVALE	D	ELSAH	B	ETIL	A	FE	D	FOLEY	D
EDGAR	B	ELSINBORO	B	ETNA		FEDORA	B	FONDA	D
EDGECUMBE	B	ELSMERE	A	ETOWAH	B	FELDA	B/D	FONDIS	C
EDGELEY	C	ELSO	D	ETOWN	B	FELIDA	B	FONTAL	C
EDGEMONT	B	EL SCLYO	C	ETTA	C	FELLOWSHIP	D	FONTREEN	B
EDGEWATER	C	ELSTON	B	ETTER	B	FELT	B	FOPIANO	D
EDGEWICK	B	ELTOPIA	B	ETTERSBURG	B	FELTA	C	FORBES	B
EDGEWOOD	A	ELTREE	B	ETTRICK	D	FELTHAM	A	FORD	D
EDGINGTON	C	ELTSAC	D	EUBANKS	B	FELTON	B	FORDNEY	A
EDINA	D	ELWHA	B	EUDORA	B	FELTONIA	B	FORDVILLE	B
EDINBURG	C	ELWOOD	C	EUFAULA	A	FENCE	B	FORE	D
EDISON	B	ELY	B	EUREKA	D	FENDALL	C	FORELAND	C
EDISTO	C	ELYSIAN	B	EUSTIS	A	FENWOOD	B	FORELLE	B
EDITH	A	ELZINGA	B	EUTAW	D	FERDELFORD	C	FORESMAN	B
EDLOE	B	EMBDEN	B	EVANGELINE	C	FERDIG	C	FORESTDALE	D
EDMONDS	C	EMDENT	C	EVANS	B	FERGUS	B	FORESTER	C
EDMORF	D	EMER	C	EVANSTON	B	FERGUSON	B	FORGAY	A
EDMUND	C	EMERALD	B	EVARD	A	FERNANDO	C	FORMAN	B
EDNA	D	EMERSON	B	EVART	D	FERNDALE	B	FORNEY	D
EDNEYVILLE	B	EMIDA	D	EVENDALE		FERNLEY	C	FORREST	C
EDOM	C	EMIGRANT	B	EVERETT	B	FERNOW	B	FORSEY	C
EDSON	C	EMIGRATION	D	EVERGLADES	A/D	FERNPOINT	C	FORSGREN	C
EDWARDS	B/D	EMILY	B	EVERLY	B	FERRELO	B	FORT COLLINS	B
EEL	C	EMLIN	B	EVERMAN	C	FERRIS	D	FORT DRUM	C
EFFINGTON	D	EMMA	C	EVERSON	C	FERRON	B	FORT LYON	B
EFWUN	A	EMMERT	A	EVESBORO	A	FERTALINE	D	FORT MEADE	A
EGAM	C	EMMET	B	EWA	B	FESTINA	B	FORT MOTT	A
EGAN	B	EMMONS	C	EWAIL	A	FETTIC	D	FORT PIERCE	C
EGBERT	B/C	EMORY	B	EWINGSVILLE	B	FIANDER	C	FORT ROCK	C
EGELAND	B	EMPEY	B	EXCHEQUER	D	FIBEA	D	FORTUNA	D
EGGLESTON	B	EMPEYVILLE	C	EXETER	C	FIDALGO	C	FORTWINGATE	C
EGNAR	C	EMPIRE	C	EXLINE	D	FIDDLETOWN	C	FORWARD	C
EICKS	C	EMRICK	B	EXRAY	D	FIDDYMENT	C	FOSHOME	B
EIFORT		ENCE	B	EXUM	C	FIELDING	B	FOSSUM	B
EKAH	C	ENCIERRO	D	EYERBOW	D	FIELDON	B	FOSTER	B/C
EKALAKA	B	ENCINA	B	EYRE	B	FIELDSON	A	FOSTORIA	B
ELAM	A	ENDERS	C			FIFE	B	FOUNTAIN	D
ELBERT	D	ENDICOTT	B	FABIUS	B	FIFER	D	FOURLOG	D
ELBURN	B	ENET	B	FACEVILLE	B	FILLMORE	D	FOURMILE	B
ELCO	B	ENFIELD	B	FAHEY	B	FINCASTLE	C	FOUR STAR	B/C
ELD	B	ENGLE	B	FAIM	C	FINGAL	C	FOUTS	B
ELDER	B	ENGLESIDE	B	FAINES	A	FINLEY	B	FOX	B
ELDER HOLLOW	D	ENGLEWOOD	C	FAIRBANKS	B	FIRESTEEL	B	FOXCREEK	C
ELDERON	B	ENGLUND	D	FAIRDALE	B	FIRGRELL	B	FOXMOUNT	C
ELDON	B	ENNIS	B	FAIRFAX	B	FIRMAGE	B	FOXOL	D
ELDORADO	C	ENOCHVILLE	B/D	FAIRFIELD	B	FIRO	C	FOXPARK	B
ELDRIDGE	C	ENOLA	B	FAIRHAVEN	B	FIRTH	B	FOXTON	C
ELEPHANT	D	ENON	C	FAIRMOUNT	D	FISH CREEK	B	FRAILEY	C
ELFROY	B	ENOS	B	FAIRPORT	C	FISHERS	B	FRAM	B
ELFRIDA	B	ENOSBURG	D	FAJARDO	C	FISHHOOK	D	FRANCIS	A
ELIJAH	C	ENSIGN	D	FALAYA	C	FISHKILL		FRANK	D
ELIOAK	C	ENSLEY	D	FALCON	C	FITCH	A	FRANKFORT	D
ELK	B	ENSTROM	B	FALFURRIAS	A	FITCHVILLE	C	FRANKIRK	C
ELKADER	B	ENTERPRISE	B	FALK	B	FITZGERALD	B	FRANKLIN	B
ELKCREEK	C	ENTIAT	D	FALKNER	C	FITZHUGH	B	FRANKSTOWN	B
ELK HOLLOW	B	ENUMCLAW	C	FALL	B	FIVE DOT	B	FRANKTOWN	D
ELKHORN	B	EPHRAIM	C	FALLBROOK	B	FIVEMILE	B	FRANKVILLE	B
ELKINS	D	EPHRATA	B	FALLON	C	FIVES	B	FRATERNIDAD	D
ELKINSVILLE	B	EPOUFETTE	D	FALLSBURG		FLAGG	B	FRAZER	C
ELKMOUND	C	EPPING	D	FALLSINGTON	D	FLAGSTAFF	C	FRED	C
ELK MOUNTAIN	B	EPSIE	D	FANCHER	C	FLAK	B	FREDENSBORG	C
ELKTON	D	ERA	B	FANG	C	FLAMING	B	FREDERICK	B
ELLABELLE	B/D	ERAM	C	FANNIN	B	FLAMINGO	D	FREDON	C
ELLEDGE	D	ERBER	C	FANNO	C	FLANAGAN	B	FREDONIA	C
ELLERY	D	ERIC	B	FANU	C	FLANDREAU	B	FREDRICKSON	C
ELLETT	D	ERIE	C	FARADAY	C	FLASHER	A	FREEBURG	C
ELLIBER	A	ERIN	B	FARALLONE	B	FLATHEAD	A	FREECE	D
ELLICOTT	A	ERNEST	C	FARAWAY	D	FLAT HORN	B	FREEHOLD	B
ELLINGTON	B	ERRAMOUSPE	D	FARGO	D	FLATTOP	D	FREEL	B
ELLINOR	B	ESCAL	B	FARISTA	B	FLAXTON	A	FREEMAN	C
ELLIOTT	C	ESCALANTE	B	FARLAND	B	FLEAK	A	FREEMANVILLE	B
ELLIS	D	ESCAMBIA	C	FARMINGTON	C/D	FLECHADO	C	FREEON	B
ELLISFORDE	C	ESCONDIDO	C	FARNUF	B	FLEETWOOD		FREER	C

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January, 1971

EXHIBIT 2-1

FREESTONE	C
FREEZENER	B
FREMONT	C
FRENCH	C
FRENCHTOWN	D
FRENEAU	
FRESNO	C
FRIANA	D
FRIANT	D
FRIOLO	C
FRIEDMAN	B
FRIES	D
FRIO	B
FRIZZELL	C
FROBERG	D
FROHMAN	C
FRONHOFER	C
FRONTON	D
FROST	D
FRUITA	B
FRUITLAND	B
FRYE	D
FUEGO	C
FUERA	C
FULDA	C
FULLERTON	B
FULMER	B/D
FULSHEAR	C
FULTON	D
FUQUAY	B
FURNIS	B/D
FURY	B/D
GAASTRA	C
GABALDON	C
GABICA	D
GACEY	D
GADDES	C
GADES	C
GADSDEN	D
GAGE	
GAGEBY	B
GAGETOWN	C
GAHEE	B
GAINES	C
GAINESVILLE	A
GALATA	D
GALE	B
GALEN	B
GALENA	C
GALEPPI	C
GALESTOWN	A
GALEY	B
GALISTEO	D
GALLAGHER	B
GALLATIN	A
GALLEGOS	B
GALLINA	C
GALLION	B
GALVA	B
GALVESTON	A
GALVIN	C
GAMBLER	A
GANNETT	D
GANSNER	D
GAPO	D
GAPPMAYER	B
GARA	B
GARBER	B
GARBUTT	B
GARCENO	C
GARDENA	B
GARDINER	A
GARDNERS FORK	B
GARDNERVILLE	D
GARCONE	A
GAREY	C
GARFIELD	C
GARITA	C
GARLAND	B
GARLET	A
GARLOCK	C
GARMON	C
GARMORE	B
GARNER	D
GARO	D
GARR	D
GARRARD	B
GARRETSON	B
GARRETT	B
GARRISON	B
GARWIN	C
GASCONADE	D
GAS CREEK	C
GASKELL	C
GASS	D
GASSET	D
GATESBURG	A
GATEVIEW	B
GATEWAY	C
GATEWOOD	D
GAULDY	B
GAVINS	C
GAVIOTA	D
GAY	D
GAYLORD	B
GAYNOR	C
GAYVILLE	B
GAZELLE	D
GAZOS	B
GEARHART	A
GEARY	B
GEE	B
GEEBURG	C
GEER	C
GEFO	A
GELKIE	B
GEM	C
GEMID	C
GEMSON	C
GENESEE	B
GENEVA	C
GENOA	D
GENOLA	B
GEORGEVILLE	B
GEORGIA	B
GERALD	D
GERBER	D
GERIG	B
GERING	B
GERLAND	C
GERMANIA	
GERMANY	B
GESTRIN	B
GETTA	C
GETTYS	C
GEYSEN	D
GHENT	C
GIBBLER	C
GIBBON	B
GIBBS	D
GIBBSTOWN	A
GIFFIN	C
GIFFORD	C
GILA	C
GILBY	B
GILCHRIST	B
GILCREST	B
GILEAD	C
GILES	B
GILFORD	B/D
GILHOULY	B
GILISPIE	C
GILLIAM	C
GILLIGAN	B
GILLS	C
GILMORE	D
GILPIN	C
GILROY	C
GILSON	B
GILT EDGE	D
GINAT	D
GINGER	C
GINI	B
GINSER	C
GIRD	A
GIVEN	C
GLADDEN	A
GLADSTONE	B
GLADWIN	A
GLAMIS	C
GLANN	B/C
GLASGOW	C
GLEAN	B
GLEASON	C
GLEN	B
GLENBERG	B
GLENBROOK	D
GLENCOE	D
GLENDALE	B
GLENDALE	B
GLENDIVE	B
GLENDORA	C
GLENELG	B
GLENFIELD	D
GLENFORD	C
GLENHALL	B
GLENHAM	B
GLENMORA	C
GLENNALLEN	C
GLENOMA	B
GLENROSE	B
GLENSTED	D
GLENTON	B
GLENVIEW	B
GLENVILLE	C
GLIDE	B
GLIKON	B
GLORIA	C
GLOUCESTER	A
GLOVER	C/D
GLYNDON	B
GLYNN	C
GOBLE	C
GODDARD	B
GODDE	D
GODECKE	D
GODFREY	C
GODWIN	D
GOEGLEIN	C
GOESSEL	D
GOFF	C
GOGEBIC	B
GOLBIN	C
GOLCONDA	D
GOLDENDALE	B
GOLDFIELD	B
GOLDHILL	B
GOLDMAN	C
GOLDRIDGE	B
GOLDRUN	A
GOLDSBORO	C
GOLDSTON	C
GOLDSTREAM	D
GOLDVALE	C
GOLDVEIN	C
GOLIAD	C
GOLLAHER	A
GOMEZ	B
GONVICK	B
GOOCH	D
GOODALE	C
GOODING	C
GOODINGTON	C
GOODLOW	B
GOODMAN	B
GOODRICH	B
GOODSPRINGS	D
GOOSE CREEK	B
GOOSE LAKE	C
GOOSMUS	B
GORDO	C
GORE	D
GORGONIO	A
GORHAM	B
GORIN	C
GORING	C
GORMAN	B
GORUS	A
GORZELL	B
GOSHEN	B
GOSHUTE	D
GOSPORT	C
GOTHAM	A
GOTHARD	D
GOTHIC	C
GOTHO	C
GOULDING	D
GOVAN	C
GOVE	B
GOWEN	B
GRABE	B
GRABLE	B
GRACEMONT	B
GRACEVILLE	B
GRACY	D
GRAFTON	B
GRAHAM	D
GRAIL	C
GRAMM	B
GRANATH	B
GRANBY	A/D
GRANDE RONDE	D
GRANDFIELD	B
GRANDVIEW	C
GRANER	C
GRANGER	C
GRANGEVILLE	B/C
GRANILE	B
GRANO	D
GRANT	B
GRANTSBURG	C
GRANTSDALE	A
GRANVILLE	B
GRAPEVINE	C
GRASMERE	B
GRASSNA	B
GRASSY BUTTE	A
GRATZ	C
GRAVDEN	C
GRAVE	B
GRAVITY	C
GRAYCALM	A
GRAYFORD	B
GRAYLING	A
GRAYLOCK	B
GRAYPOINT	B
GRAYS	B
GREAT BEND	B
GREELEY	B
GREEN BLUFF	B
GREEN CANYON	B
GREENCREEK	B
GREENDALE	B
GREENFIELD	B
GREENHORN	D
GREENLEAF	B
GREENOUGH	C
GREENPORT	
GREEN RIVER	B
GREENSBORO	
GREENSON	C
GREENTON	C
GREENVILLE	B
GREENWATER	A
GREENWICH	B
GREENWOOD	D
GREER	C
GREGORY	A
GRELL	C
GRENADA	C
GRENVILLE	B
GRESHAM	C
GREWINGK	C
GREYBACK	B
GREYBULL	C
GREYCLIFF	C
GRIFFY	B
GRIGSTON	B
GRIPSTAD	B
GRISWOLD	B
GRIVER	C
GRIZZLY	C
GROGAN	B
GROSECLOSE	C
GROSS	C
GROTON	A
GROVE	A
GROVELAND	B
GROVER	B
GROVETON	B
GRUBBS	D
GRULLA	D
GRUMMIT	C
GRUNDY	C
GRUVER	C
GRYGLA	C
GUADALUPE	B
GUAJE	A
GUALALA	D
GUAMANI	B
GUANAJIBO	C
GUANICA	D
GUAYABO	B
GUAYABOTA	D
GUAYAMA	D
GUBEN	B
GUCKEEN	C
GUELPH	B
GUENOC	C
GUERNSEY	C
GUERRERO	C
GUEST	D
GUIN	A
GULER	B
GULKANA	B
GUMBOTOT	C
GUNBARREL	A
GUNN	B
GUNTER	A
GURABO	D
GURNEY	C
GUSTAVUS	B
GUSTIN	C
GUTHRIE	D
GUYTON	D
GWIN	D
GWINNETT	B
GYMER	C
HACOKE	C
HACIENDA	C
HACK	B
HACKERS	B
HACKETTSTOWN	B
HADLEY	B
HADO	B
HAGEN	B
HAGENBARTH	B
HAGENER	A
HAGER	C
HAGERMAN	B
HAGERSTOWN	C
HAGGA	B
HAIG	C
HAIKU	B
HAILMAN	B
HAINES	B/C
HAIRE	C
HALAWA	B
HALDER	C
HALE	B
HALEIWA	B
HALEY	B
HALF MOON	B
HALFORD	A
HALFWAY	D
HALII	B
HALIIMAILE	B
HALIS	B
HALL	B
HALLECK	B
HALL RANCH	C
HALLVILLE	B
HALSEY	D
HAMAKUAPOKO	B
HAMAN	B
HAMAR	B
HAMBLEN	C
HAMBRIGHT	D
HAMBURG	B
HAMEL	C
HAMERLY	C
HAMILTON	A
HAMLET	B
HAMLIN	B
HAMPDEN	
HAMPSHIRE	C
HAMPTON	C
HAMTAH	C
HANA	A
HANALEI	C
HANAMAULU	A
HANCEVILLE	B
HAND	B
HANDFORD	B
HANEY	B
HANGAARD	C
HANGER	B
HANIPOE	B
HANKINS	C
HANKS	B
HANLY	A
HANNA	B
HANOVER	C
HANS	C
HANSEL	C
HANSKA	C
HANSON	A
HANTHO	B
HANTZ	D
HAP	B
HAPGOOD	B
HAPNEY	C
HARBORD	B
HARBOURTON	
HARCO	B
HARDEMAN	B
HARDESTY	B
HARDING	D

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EXHIBIT 2-1

January, 1971

HARDSCRABBLE	B
HARDY	D
HARGREAVE	B
HARKERS	C
HARKEY	B
HARLAN	B
HARLEM	C
HARLESTON	C
HARLINGEN	D
HARMEHL	C
HARMONY	C
HARNEY	C
HARPETH	B
HARPS	B
HARPSTER	C
HARPT	B
HARQUA	B
HARQUA	B
HARRIET	D
HARRIMAN	B
HARRIS	D
HARRISBURG	D
HARRISON	C
HARRISVILLE	C
HARSTENE	B
HART	D
HART CAMP	C
HARTFORD	A
HARTIG	B
HARTLAND	B
HARTLETON	B
HARTLINE	B
HARTSBURG	B
HARTSELLS	B
HARTSHORN	B
HARVARD	B
HARVEL	B
HARVEY	C
HASKILL	A
HASKINS	C
HASSELL	D
HASTINGS	B
HAT	B
HATBORO	D
HATCH	C
HATCHERY	C
HATFIELD	C
HATHAWAY	B
HATTIE	C
HATTON	C
HAUBSTADT	C
HAVANA	B
HAVEN	B
HAVERLY	B
HAVERSON	B
HAVILLAH	B
HAVINGDON	C
HAVRE	B
HAVRELON	B
HAW	B
HAWES	A
HAWI	B
HAWKEYE	A
HAWKSELL	A
HAWKSPRINGS	B
HAXTUN	A
HAYBOURNE	B
HAYBRO	C
HAYDEN	B
HAYESTON	B
HAYESVILLE	B
HAYFIELD	B
HAYFORD	C
HAYMOND	B
HAYNESS	D
HAYNIE	B
HAYPRESS	A
HAYSPUR	B/D
HAYTER	B
HAYTI	D
HAYWOOD	B
HAZEL	C
HAZELAIR	D
HAZEN	B
HAZLEHURST	C
HAZLETON	B
HEADLEY	B
HEADQUARTERS	B
HEAKE	D
HEATH	C
HEATLY	A
HEBBRONVILLE	B
HEBER	B
HEBERT	C
HEBGEN	A
HEBO	D
HEBRON	C
HECHT	B
HECKI	C
HECLA	B
HECTOR	D
HEDDON	C
HEDRICK	B
HEDVILLE	D
HEGNE	D
HEIDEN	D
HEIDTMAN	C
HEIL	D
HEIMDAL	B
HEISETON	B
HEISLER	B
HEIST	B
HEITT	C
HEITZ	D
HEIZER	D
HELDT	C
HELEMANO	C
HELENA	C
HELMER	C
HELVETIA	C
HELY	B
HEMBRE	B
HEMMI	C
HEMPFIELD	
HEMPSTEAD	C
HENCRATT	B
HENDERSON	B
HENDRICKS	B
HENEFER	C
HENKIN	B
HENLEY	C
HENLINE	C
HENNEKE	C
HENNEPIN	B
HENNINGSEN	C
HENRY	D
HENSEL	B
HENSHAW	C
HENSLEY	D
HEPLER	D
HERBERT	B
HEREFORD	B
HERKIMER	B
HERLONG	D
HERMISTON	B
HERMON	A
HERNDON	B
HERO	B
HERRERA	A
HERRICK	C
HERRON	B
HERSH	A
HERSHAL	B/D
HESCH	B
HESPER	C
HESPERIA	B
HESPERUS	B
HESSE	C
HESSEL	C
HESSELBERG	C
HESSELTINE	B
HESSON	C
HETTINGER	D
HEXT	B
HEZEL	B
HIALEAH	D
HIAWATHA	A
HIBBARD	C
HIBBING	C
HICKORY	C
HICKS	B
HIDALGO	B
HIDEAWAY	D
HIDEWOOD	C
HIGHAMS	D
HIGHFIELD	B
HIGH GAP	C
HIGHLAND	B
HIGHMORE	B
HIGH PARK	B
HIHIMANU	A
HIIBNER	C
HIKO PEAK	B
HIKO SPRINGS	D
HILDRETH	D
HILEA	D
HILES	B
HILGER	B
HILGRAVE	B
HILLEMANN	C
HILLET	D
HILLFIELD	B
HILLGATE	C
HILLIARD	B
HILLON	B
HILLSBORO	B
HILLSDALE	B
HILMAR	C/D
HILO	A
HILT	B
HILTON	B
HINCKLEY	A
HINDES	C
HINESBURG	C
HINKLE	D
HINMAN	C
HINSDALE	
HINTZE	D
HISLE	D
HITT	B
HI VISTA	C
HIWASSEE	B
HIWOOD	A
HIXTON	B
HOBACKER	B
HOBAN	C
HOBBS	B
HOBSON	C
HOCHHEIM	B
HOCKING	B
HOCKINSON	C
HOCKLEY	C
HODGE	B
HODGINS	C
HODGSON	C
HOEBE	B
HOELZLE	C
HOFFMAN	C
HOFFMANVILLE	C
HOGANSBURG	B
HOGELAND	B
HOGG	D
HOGRIS	B
HOH	B
HOHMANN	C
HOKO	C
HOLBROOK	B
HOLCOMB	D
HOLDAWAY	D
HOLDEN	A
HOLDERNESS	C
HOLDREGE	B
HOLLAND	B
HOLLINGER	B
HOLLIS	C/D
HOLLISTER	D
HOLLOMAN	C
HOLLOWAY	A
HOLLY	D
HOLLY SPRINGS	D
HOLLYWOOD	D
HOLMDEL	C
HOLMES	B
HOLOPUA	B
HOLOPAW	B/D
HOLROYD	B
HOLSINE	B
HOLST	B
HOLSTON	B
HOLT	B
HOLTLE	B
HOLTVILLE	C
HOLYOKE	C/D
HOMA	C
HOME CAMP	C
HOMELAKE	B
HOMER	C
HOMESTAKE	D
HOMESTEAD	B
HONAUNAU	C
HONCUT	B
HONDALE	D
HONDO	C
HONDOHO	B
HONEOYE	B
HONEY	D
HONEYGROVE	C
HONEYVILLE	C
HONN	B
HONOKAA	A
HONOLUA	B
HONOMANU	B
HONOULIULI	D
HONUAULU	A
HOOD	B
HOODLE	B
HOODSPORT	B
HOODVIEW	B
HOOKTON	C
HOOLEHUA	B
HOOPAL	D
HOOPER	D
HOOPESTON	B
HOOSIC	A
HOOT	D
HOOTEN	D
HOOVER	B
HOPETON	C
HOPEWELL	
HOPGOOD	C
HOPKINS	B
HOPLEY	B
HOPPER	B
HOQUIAM	B
HORATIO	D
HORD	B
HOREB	B
HORNELL	D
HORNING	A
HORNITOS	D
HORROCKS	B
HORSESHOE	B
HORTON	B
HORTONVILLE	B
HOSKIN	C
HOSLEY	D
HOSMER	C
HOTAW	C
HOT LAKE	C
HOUDEK	B
HOUGHTON	A/D
HOUK	C
HOULKA	D
HOULTON	C/D
HOUNDBY	D
HOURGLASS	B
HOUSATONIC	D
HOUSE MOUNTAIN	D
HOUSEVILLE	C
HOUSTON	D
HOUSTON BLACK	D
HOVDE	A/C
HOVEN	D
HOVENWEEP	C
HOVERT	D
HOVEY	C
HOWARD	B
HOWELL	C
HOWLAND	C
HOYE	B
HOYLETON	C
HOYPUS	A
HOYTVILLE	D
HUBBARD	A
HUBER	D
HUBERT	B
HUBLERSBURG	C
HUCKLEBERRY	C
HUDSON	C
HUECO	C
HUEL	A
HUENEME	B/C
HUERHUERO	D
HUEY	D
HUFFINE	A
HUGGINS	C
HUGHES	C
HUGHESVILLE	B
HUGO	B
HUICHICA	C
HUIKAU	A
HULETT	B
HULLS	C
HULLT	B
HULUA	D
HUM	B
HUMACAO	B
HUMATAS	C
HUMBARGER	B
HUMBIRD	C
HUMBOLDT	C
HUMDUN	B
HUME	C
HUMESTON	C
HUMMINGTON	C
HUMPHREYS	B
HUMPTULIPS	B
HUNSAKER	B
HUNTERS	B
HUNTING	C
HUNTINGTON	B
HUNTSVILLE	B
HUPP	B
HURLEY	D
HURON	C
HURST	D
HURWAL	B
HUSE	C
HUSSA	B/D
HUSSMAN	D
HUTCHINSON	C
HUTSON	B
HUXLEY	D
HYAM	D
HYAT	A
HYATTVILLE	B
HYDABURG	D
HYDE	D
HYDRO	C
HYMAS	D
HYRUM	B
HYSHAM	D
IAO	C
IBERIA	D
ICENE	C
IDA	B
IDABEL	B
IDANA	C
IDEON	D
IDMON	B
IGNACIO	B
IGO	D
IGUALDAD	D
IHLEN	D
IJAM	C
ILDEFONSO	B
ILKA	B
ILLION	B/D
IMA	B
IMBLER	B
IMLAY	C
IMMOKALEE	B/D
IMPERIAL	C
INAVALE	A
INDIAHOMA	D
INDIAN	
INDIAN CREEK	D
INDIANO	C
INDIANOLA	A
INDIO	B
INGA	B
INGALLS	B
INGARD	B
INGENIO	C
INGRAM	D
INKLER	B
INKS	D
INMAN	C
INMO	A
INSKIP	C
INVERNESS	D
INWOOD	C
IO	B
IOLA	A
IOLEAU	C
IONA	B
IONIA	B
IOSCO	B
IPAVA	B
IRA	C
IREDELL	D
IRETEBA	C
IRIM	C
IROCK	B
IRON BLOSSOM	D
IRON MOUNTAIN	D
IRON RIVER	B
IRONTON	C
IRVINGTON	C

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EXHIBIT 2-1

January, 1971

IRWIN	D	JONUS	B	KARLO	D	KERMIT	A	KITSAP	C
ISAAC	C	JOPLIN	B	KARLUK	C	KERR	B	KITTANNING	
ISAAQUAH	B/C	JOPPA	B	KARNAK	D	KERRICK	B	KITTITAS	B
ISABELL	C	JORDAN	D	KARNES	B	KERRTOWN		KITTREDGE	C
ISAN	D	JORNADO	B	KARRO	B	KERSHAW	A	KITTSON	C
ISANTI	D	JORY	C	KARS	A	KERSICK	D	KIUP	B
ISHAM	C	JOSE	C	KARTA	C	KERSTON	A/D	KIVA	B
ISHI PISHI	C	JOSEPHINE	B	KARTAR	B	KERT	C	KIWANIS	A
ISLAND	B	JOSIE	B	KASHWITNA	B	KERWIN	C	KIZHUYAK	B
ISOM	B	JOY	B	KASILOF	A	KESSLER	C	KJAR	D
ISTOKPOGA	D	JUBILEE	C	KASKI	B	KESWICK	D	KLABER	C
ITSWOOT	B	JUDD	D	KASOTA	C	KETCHLY	B	KLAMATH	B/D
IUKA	C	JUDITH	B	KASSLER	A	KETTLE	B	KLAUS	A
IVA	C	JUDKINS	C	KASSON	C	KETTLEMAN	B	KLAWASI	D
IVAN	B	JUDSON	B	KATAMA	B	KETTNER	C	KLEJ	B
IVES	B	JUDY	C	KATEMCY	C	KEVIN	C	KLICKER	C
IVIE	A	JUGET	D	KATO	C	KEWAUNEE	C	KLICKITAT	C
IVINS	C	JUGHANDLE	B	KATHINE	B	KEWEENAW	A	KLINE	B
IZAGORA	C	JULES	B	KATULA	B	KEYA	B	KLINESVILLE	C/D
IZEE	C	JULESBURG	A	KATY	C	KEYES	D	KLINGER	B
		JULIAETTA	B	KAUFFMAN	D	KEYPORT	C	KLONDIKE	D
JABU	C	JUMPE	B	KAUPO	A	KEYTESVILLE	D	KLONE	B
JACAGUAS	B	JUNCAL	C	KAVETT	D	KEZAR	B	KLOOCHMAN	B
JACANA	D	JUNCOS	D	KAWAIHAE	C	KIAWAH	C	KLOTEN	B
JACINTO	B	JUNCTION	B	KAWAIHAPAI	B	KIBBIE	B	KLUTINA	B
JACK CREEK	B	JUNEAU	B	KAWBAWGAM	C	KICKERVILLE	B	KNAPPA	B
JACKLIN	B	JUNIATA		KAWICH	A	KIDD	D	KNEELAND	C
JACKNIFE	C	JUNIUS	C	KAWKAWLIN	C	KIDMAN	B	KNIFFIN	C
JACKS	D	JUNO	B	KEAAU	D	KIEHL	A	KNIGHT	C
JACKSON	B	JUNQUITOS	C	KEAHUA	B	KIEV	B	KNIK	B
JACKSONVILLE	C	JURA	C	KEALAKEKUA	C	KIKONI	B	KNIPPA	D
JACOB	D	JUVA	B	KEALIA	D	KILARC	D	KNOB HILL	B
JACOBSEN	D	JUVAN	D	KEANSBURG	D	KILAUEA	B	KNOWLES	B
JACOBY	C			KEARNS	B	KILBOURNE	A	KNOX	B
JACQUES	C	KAALUALU	A	KEATING	C	KILBURN	A	KNULL	B
JACQUITH	C	KACHEMAK	B	KEAUKAHA	D	KILCHIS	C	KNUTSEN	A
JACWIN	B	KADASHAN	B	KEAWAKAPU	B	KILDOR	C	KOBAR	C
JAFFREY	A	KADE	C	KEBLER	B	KILGORE	B/D	KOCH	C
JAGUEYES	B	KADOKA	B	KECH	C	KILKENNY	B	KODAK	C
JAL	B	KAUCKA	B	KECKO	B	KILLBUCK	C/D	KODIAK	B
JAMES CANYON	B/C	KAENA	D	KEDRON	C	KILLEY	B	KOEHLER	C
JAMESTOWN	C	KAHALUU	D	KEEFERS	C	KILLINGWORTH		KOELE	B
JANE	C	KAHANA	B	KEEGAN		KILLPACK	C	KOEPKE	B
JANISE	C	KAHANUI	B	KEEI	D	KILMERQUE	C	KOERLING	B
JANSEN	A	KAHLER	B	KEEKEE	B	KILOA	A	KOGISH	D
JARBOE	C	KAHOLA	B	KEENE	C	KILOHANA	A	KOHALA	A
JARITA	C	KAH SHEETS	D	KEENO	C	KILWINNING	C	KOKEE	B
JARRE	B	KAHUA	D	KEG	B	KIM	B	KOKO	B
JARVIS	B	KAIKLI	D	KEHENA	C	KIMAMA	B	KOKOKAHI	D
JASPER	B	KAILUA	A	KEIGLEY	C	KIMBALL	C	KOKOMO	B/D
JAUCAS	A	KAIMU	A	KEISER	B	KIMBERLY	B	KOLBERG	B
JAVA	B	KAINALIU	A	KEITH	B	KIMBROUGH	D	KOLEKOLE	C
JAY	C	KAIPOIOI	B	KEKAHA	B	KIMMERLING	D	KOLLS	D
JAYEM	B	KAIWIKI	A	KEKAKE	D	KIMO	C	KOLOA	C
JAYSON	D	KALAE	B	KELLER	C	KINA	D	KOLOKOLO	B
JEAN	A	KALAMA	C	KELLY	D	KINCO	A	KONA	D
JEANERETTE	D	KALAMAZOO	B	KELN	C	KINGFISHER	B	KONAWA	B
JEAN LAKE	B	KALAPA	B	KELSEY	C	KINGHURST	B	KONNER	C
JEDDO	D	KALAUPAPA	D	KELSO	C	KINGMAN	D	KONOKTI	C
JEFFERSON	B	KALIFONSKY	C	KELTNER	B	KINGS	C/D	KOOLAU	C
JEKLEY	C	KALIHI	D	KELVIN	C	KINGSBURY	D	KOOSKIA	C
JELM	B	KALISPELL	A	KEMOO	B	KINGSLEY	B	KOOTENAI	A
JENKINS	B	KALKASKA	A	KEMPSVILLE	B	KINGS RIVER	C	KOPIAH	C
JENKINSON	D	KALMIA	B	KEMPTON	B	KINGSTON	B	KOPP	B
JENNESS	B	KALOKO	D	KENAI	C	KINGSVILLE	C	KOPPES	B
JENNINGS	C	KALOLOCH	B	KENANSVILLE	A	KINKEAD	D	KORCHEA	B
JENNY	D	KALSIN	C	KENDAIA	C	KINKEL	B	KORNMAN	B
JERAULD	D	KAMACK	B	KENDALL	B	KINKORA	D	KOSMOS	C
JERICHO	C	KAMAKOA	A	KENDALLVILLE	B	KINMAN	C	KOSSE	D
JEROME	B	KAMAOA	B	KENESAW	B	KINNEY	B	KOSTER	C
JERRY	C	KAMACLE	B	KENMOOR	B	KINNICK	C	KOSZTA	B
JESBEL	D	KAMRAR	B	KENNALLY	B	KINREAD	D	KOUTS	B
JESSE CAMP	C	KANABEC	B	KENNAN	B	KINROSS	D	KOVICH	C
JESSUP	C	KANAKA	B	KENNEBEC	B	KINSTON	D	KOYEN	B
JETT	B	KANAPAHA	A/D	KENNEDY	B	KINTON	C	KOYUKUK	B
JIGGS	C	KANDIK	B	KENNEWICK	B	KINZEL	B	KRADE	B
JIM	C	KANE	B	KENNEY	A	KIONA	B	KRANZBURG	B
JIMENEZ	C	KANECHE	B	KENNEY LAKE	C	KIPLING	D	KRATKA	C
JIMTOWN	C	KANEPUU	B	KENO	D	KIPP	C	KRAUSE	A
JOB	C	KANLEE	B	KENOMA	D	KIPPEN	B	KREAMER	
JOBOS	C	KANOSH	C	KENSAL	B	KIPSON	C	KREPLIN	B
JO CITY	B	KANZA	D	KENSPUR	A	KIRK	B/D	KRENTZ	B
JOEL	B	KAPAA	A	KENT	D	KIRKHAM	C	KRESSON	C
JOES	B	KAPAPALA	B	KENYON	C	KIRKLAND	D	KRUM	D
JOHNS	C	KAPOD	B	KEO	B	KIRKTON	B	KRUSE	B
JOHNSBURG	D	KAPOWSIN	B	KEOLDAR	B	KIRTLEY	B	KRUZOF	B
JOHNSON	B	KAPUHIKANI	C	KEOMAH	C	KIRVIN	C	KUBE	B
JOHNSTON	B/D	KARAMIN	B	KEOTA	C	KISRING	D	KUBLER	C
JOHNSWOOD	B	KARDE	C	KEOWNS	D	KISSICK	D	KUBLI	C
JOICE	D	KARHEEN	C	KEPLER	C	KISTLER	C/D	KUCERA	B
JOLIET	C	KARLAN	C	KERBY	B	KITCHELL	B	KUCK	C
JONESVILLE	A	KARLIN	A	KERMEL	B	KITCHEN CREEK	B	KUHL	D

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KUKATAU	A	LANE	C	LEADVILLE	B	LICKDALE	D	LOLAK	D
KULA	B	LANEY	B	LEAF	D	LICKING	C	LOLALITA	B
KULAKALA	B/C	LANG	B/D	LEAHY	B	LICKSKILLET	D	LOLEKAA	B
KULLIT	B	LANGFORD	C	LEAL	B	LIDDELL	D	LOLETA	C/D
KUMA	B	LANGHEI	B	LEAPS	C	LIEBERMAN	C	LOLO	A
KUNIA	B	LANGLEY	C	LEATHAM	C	LIEN	D	LOLON	A
KUNUWEIA	C	LANGLOIS	D	LEAVENWORTH	B	LIGGET	B	LOMA	C
KUNO	D	LANGOLA	B	LEAVITT	B	LIGHTNING	D	LOMALTA	D
KUSKOKWIM	D	LANGRELL	B	LEAVITTVILLE	B	LIGNUM	C	LOMAX	B
KUSLINA	D	LANGSTON	C	LEBANON	C	LIGON	D	LOMIRA	B
KUTCH	D	LANIER	B	LEBAR	B	LIHEN	A	LONDO	C
KUTZTOWN	B	LANIGER	B	LEBEC	B	LIHUE	B	LONEPINE	C
KVICHAK	B	LANKBUSH	B	LEBO	C	LIKES	A	LONERIDGE	B
KYLE	D	LANKIN	C	LEBSACK	C	LILAH	A	LONE ROCK	A
KYLER	D	LANKTREE	C	LECK KILL	B	LILLIWAUP	A	LONETREE	B
		LANOAK	B	LEDBEDER	B	LIMA	B	LONGFORD	C
LA BARGE	B	LANSDALE	B	LEDGEFORK	A	LIMANI	B	LONGLOIS	B
LABETTE	C	LANSDOWNE		LEDGER	C	LIMBAR	B	LONGMARE	B
LABISH	D	LANSING	B	LEDRU	D	LIMERICK	C	LONGMONT	C
LA BOUNTY	C	LANTIS	B	LEDY		LIMON	C	LONGRIE	C
LA BRIER	C	LANTON	C	LEE	D	LIMONES	B	LONGVAL	B
LACAMAS	C/D	LANTONIA	B	LEEDS	C	LINCOLN	A	LONG VALLEY	B
LA CASA	C	LANTZ	D	LEEFIELD	C	LINCROFT	A	LONGVIEW	C
LACITA	C	LAP	D	LEELANAU	A	LINDLEY	C	LONOKE	B
LACKAWANNA	C	LAPALMA	C	LEEPER	D	LINDSEY	D	LONTI	C
LACONA	C	LAPEER	B	LEESVILLE	B/C	LINDSIDE	C	LOOKOUT	C
LACOTA	D	LAPINE	A	LEETON	C	LINDSTROM	B	LOON	B
LACY	D	LAPLATTA	C	LEETONIA	C	LINDY	C	LOPER	B
LADD	B	LAPORTE	C	LEFOR	B	LINEVILLE	C	LOPEZ	D
LADDER	D	LA POSTA	A	LEGLER	B	LINGANORE	B	LORADALE	C
LADELLE	B	LA PRAIRIE	B	LEGORE	B	LINKER	B	LORAIN	C/D
LADOGA	C	LARABEE	B	LEHEW	C	LINKVILLE	B	LORDSTOWN	C
LADUE	C	LARCHMOUNT	B	LEHIGH	C	LINNE	C	LORELLA	D
LADYSMITH	D	LARDELL	C	LEHMANS	D	LINNET	D	LORENZO	A
LA FARGE	B	LAREDO	B	LEHR	B	LINNEUS	B	LORETTO	B
LAFE	D	LARES	C	LEICESTER	C	LINO	C	LORING	C
LA FONDA	C	LARGENT	D	LEILEHUA	B	LINSLAW	D	LOS ALAMOS	C
LAFONT	B	LARGO	C	LELA	D	LINT	B	LOS BANOS	C
LAGLORIA	B	LARIMER	B	LELAND	D	LINTON	B	LOSEE	B
LAGONDA	C	LARKIN	B	LEMETA	D	LINVILLE	B	LOS GATOS	B
LA GRANDE	C	LARKSON	C	LEMPSTER	C/D	LINWOOD	A/D	LOS GUINEOS	C
LAHAINA	B	LA ROSE	B	LEN	C	LIPAN	D	LOS OSOS	C
LA HOGUE	B	LARRY	D	LENA	A	LIPPINCOTT	B/D	LOS ROBLES	B
LAHONTAN	D	LARSON	D	LENAPAH	D	LIRIOS	B	LOS TANOS	B
LAIDIG	C	LARUE	A	LENAWEE	B/D	LIRRET	D	LOST CREEK	B
LAIDLAW	B	LARVIE	D	LENNEP	D	LISADE	B	LOST HILLS	C
LAIRDSVILLE	D	LAS	C	LENOIR	D	LISAM	D	LOS TRANCOS	D
LAIREP	D	LAS ANIMAS	C	LENOX	B	LISBON	B	LOSTWELLS	B
LA JARA	C	LASAUSSES	C	LENZ	B	LISMAS	D	LOTHAIR	C
LAKE	A	LAS FLORES	D	LEO	B	LISMORE	B	LOTUS	B
LAKE CHARLES	D	LASHLEY		LEON	A/D	LITCHFIELD	A	LOUDON	C
LAKE CREEK	B	LASIL	D	LEONARD	C	LITHGOW	C	LOUDONVILLE	C
LAKEHELEN	B	LAS LUCAS	C	LEONARDO	B	LITHIA	C	LOUIE	C
LAKEHURST	A	LAS POSAS	C	LEONARDTOWN	D	LITIMBER	C	LOUISA	B
LAKE JANEE	A	LASSEN	C	LEONIDAS	B	LITLE	D	LOUISBURG	B
LAKELAND	A	LASTANCE	B	LEOTA	C	LITTLEBEAR	A	LOUP	D
LAKEMONT	D	LAS VEGAS	D	LEPLEY	D	LITTLEFIELD	D	LOURDES	C
LAKEPORT	B	LATAH	C	LERDAL	C	LITTLE POLE	D	LOUVIERS	D
LAKESHORE	D	LATAHCO	C	LEROY	B	LITTLETON	B	LOVEJOY	C
LAKESOL	B	LATANIER	D	LESHARA	B	LITTLE WOOD	B	LOVELAND	C
LAKETON	B	LATHAM	D	LESHO	C	LITZ	C	LOVELL	C
LAKEVIEW	C	LATINA	D	LESLIE	D	LIVERMORE	A	LOVELOCK	C/C
LAKEWIN	A	LATOM	D	LESTER	B	LIVINGSTON	D	LOWELL	C
LAKEWOOD	A	LATONIA	B	LE SUEUR	B	LIVONA	A	LOWRY	B
LAKI	B	LATTY	C	LETA	C	LIZE	C	LOWVILLE	B
LAKIN	A	LAUDERDALE	B	LETCHER	D	LIZZANT	B	LOYAL	B
LAKOMA	D	LAUGENOUR	B/D	LETHA	D	LOBDELL	C	LOYALTON	D
LALAAU	A	LAUGHLIN	B	LETHENT	C	LOBELVILLE	C	LOYSVILLE	D
LA LANDE	C	LAUMAIA	B	LETORT		LOBERG	B	LOZANO	B
LALLIE	D	LAUREL	C	LETTERBOX	B	LOBERT	B	LOZIER	D
LAM	B/D	LAURELHURST	C	LEVAN	A	LOBITOS	C	LUALUALEI	D
LAMAR	B	LAURELWOOD	B	LEVASY	C	LOCEY	C	LUBBOCK	C
LAMARTINE	B	LAUREN	B	LEVERETT	C	LOCHSA	B	LUBRECHT	C
LAMBERT	B	LAVALLEE	B	LEVIATHAN	B	LOCKE	B	LUCAS	C
LAMBETH	C	LAVEEN	B	LEVIS	C	LOCKERBY	C	LUCE	C
LAMINGTON	D	LAVELDO	D	LEWIS	D	LOCKHARD	B	LUCEDALE	B
LAMO	B	LAVERKIN	C	LEWISBERRY	B	LOCKHART	B	LUCERNE	B
LAMONI	D	LAVINA	C	LEWISBURG	C	LOCKPORT	D	LUCIEN	C
LAMONT	A	LAWAI	B	LEWISTON	C	LOCKWOOD	B	LUCILE	B
LAMONIA	C	LAWLER	B	LEWISVILLE	C	LOCUST	C	LUCILETON	B
LAMOURE	C	LAWRENCE	C	LEX	B	LODAR	D	LUCKY	B
LAMPHIER	B	LAWRENCEVILLE	C	LEXINGTON	B	LODEMA	A	LUCKY STAR	B
LAMPSHIRE	D	LAWSON	B	LIBBINGS	D	LODI	C	LUCY	A
LAMSON	D	LAWTHER	D	LIBBY	B	LODO	D	LUDDEN	D
LANARK	B	LAWTON	C	LIBEG	A	LOFFTUS	C	LUDLOW	C
LANCASTER	B	LAX	C	LIBERAL	D	LOFTON	D	LUFKIN	D
LANCE	B	LAYCOCK	B	LIBERTY	C	LOGAN	C	LUHON	B
LAND	D	LAYTON	A	LIBORY	A	LOGGERT	A	LUJANE	C
LANDES	B	LEA	C	LIBRARY	D	LOGY	B	LUKIN	C
LANDISBURG	C	LEADER	B	LIBUTTE	D	LOHLER	C	LULA	B
LANDLOW	C	LEADPOINT	B	LICK	B	LOHMILLER	C	LUMBEE	D
LANDUSKY	D	LEADVALE	C	LICK CREEK	D	LOHNES	A	LUMMI	B/C

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January, 1971

EXHIBIT 2-1

LUN	C	MALABAR	A/D	MARKSBORO		MAYFLOWER	C	MCVICKERS	C
LUNA	C	MALABON	C	MARLA	A	MAYHEW	D	MEAD	D
LUNCH	C	MALACHY	B	MARLBORO	B	MAYLAND	B	MEADIN	A
LUNDIMO	C	MALAGA	B	MARLEAN	B	MAYMEN	D	MEADOWVILLE	B
LUNDY	B	MALAMA	A	MARLETTE	B	MAYNARD LAKE	B	MEADVILLE	
LUNT	C	MALAYA	D	MARLEY	B	MAYO	B	MEANDER	D
LUPTON	D	MALCOLM	B	MARLIN	D	MAYODAN	B	MECAN	B
LURA	D	MALEZA	B	MARLOW	C	MAYOWORTH	D	MECCA	B
LURAY	C/D	MALIBU	D	MARLTON	C	MAYSDORF	B	MECKESVILLE	C
LUTE	D	MALIN	C/D	MARMARTH	B	MAYSVILLE		MECKLENBURG	C
LUTH	C	MALJAMAR	A	MARNA	D	MAYTOWN	C	MEDA	B
LUTHER	B	MALLOT	A	MARPA	B	MAYVILLE	B	MEDANO	C
LUTIE	B	MALM	C	MARQUETTE	A	MAYWOOD	B	MEDARY	C
LUTON	D	MALO	B	MARR	B	MAZEPPA	B	MEDFORD	B
LUVERNE	C	MALONE	B	MARRIOTT	B	MAZON	C	MEDFRA	D
LUXOR	C	MALOTERRE	D	MARSDEN	C	MAZUMA	C	MEDICINE LODGE	B
LUZENA	D	MALPAIS	C	MARSELL	B	MCAFEE	C	MEDINA	B
LYCAN	B	MALPOSA	C	MARSHALL	B	MCALLEN	B	MEDWAY	B
LYCOMING	C	MALVERN	C	MARSHAN	D	MCALLISTER	C	MEEKS	A
LYDICK	B	MAMALA	D	MARSHDALE	C	MCALPIN	C	MEETEETSE	C
LYFORD	C	MAMOU	C	MARSHFIELD	C	MCBEE	B	MEGGETT	D
LYLES	B	MANAHAA	C	MARSING	B	MCBETH	C	MEGON	C
LYMAN	C/D	MANALAPAN		MART	C	MCBRIDE	B	MEHL	C
LYNCH	D	MANANA	C	MARTELLA	B	MCCABE	B	MEHLHORN	C
LYNCHBURG	B/D	MANASSA	C	MARTIN	C	MCCAFFERY	A	MEIGS	
LYNDEN	A	MANASSAS	B	MARTINA	A	MCCAIN	C	MEIKLE	D
LYNNDYL	A	MANASTASH	C	MARTINECK	D	MCCALEB	B	MEISS	D
LYNN HAVEN	B/D	MANATEE	B/D	MARTINEZ	D	MCCALLY	D	MELBOURNE	B
LYNNVILLE	C	MANAWA	C	MARTINI	B	MCCAMMON	C	MELBY	C
LYNX	B	MANCELONA	A	MARTINSBURG	B	MCCARRAN	D	MELITA	B
LYONMAN	C	MANCHESTER	A	MARTINSDALE	B	MCCARTHY	B	MELLENTHIN	D
LYONS	D	MANDAN	B	MARTINSON	D	MCCLAVE	C	MELLOR	D
LYONSVILLE	B	MANDERFIELD	B	MARTINSVILLE	B	MCCLEARY	C	MELLOTT	B
LYSINE	D	MANDEVILLE	B	MARTINTON	C	MCCLELLAN	B	MELOLAND	C
LYSTAIR	B	MANFRED	C	MARTY	B	MCCLOUD	C	MELROSE	C
LYTELL	B	MANGUM	D	MARVAN	D	MCCOIN	D	MELSTONE	A
		MANHATTAN	A	MARVIN	C	MCCOLL	D	MELTON	B
MABEN	C	MANHEIM	C	MARY	C	MCCONNEL	B	MELVILLE	B
MABI	D	MANI	C	MARYDEL	B	MCCOOK	B	MELVIN	D
MABRAY	D	MANILA	C	MARYSLAND	D	MCCORMICK	C	MEMALOOSE	D
MACAY	B	MANISTEE	B	MASADA	C	MCCOY	C	MEMPHIS	B
MACEDONIA	C	MANITOU	C	MASCAMP	D	MCCREE	B	MENAHGA	A
MACHETE	C	MANLEY	B	MASCOTTE	D	MCCRORY	D	MENAN	C
MACHIAS	B	MANLIUS	C	MASHEL	B	MCCROSKIE	D	MENARD	B
MACK	C	MANLOVE	B	MASHULAVILLE	B/D	MCCULLOUGH	C	MENCH	C
MACKEN	D	MANNING	B	MASON	B	MCCULLY	C	MENDEBOURE	C
MACKINAC	B	MANOR	B	MASONVILLE	C	MCCUNE	D	MENDOCINO	B
MACKSBURG	B	MANSFIELD		MASSACK	B	MCCUTCHEN	C	MENDON	B
MACOMB	B	MANSIC	B	MASSENA	C	MCDOLE	B	MENDOTA	B
MACOMBER	B	MANSKER	B	MASSILLON	B	MCDONALD	B	MENEFEE	D
MACON	B	MANTACHIE	C	MASTERSON	B	MCDONALDSVILLE	C	MENFRO	B
MACY	B	MANTEO	C/D	MATAMOROS	C	MCEWEN	B	MENLO	D
MADALIN	D	MANTER	B	MATANUSKA	C	MCFADDEN	B	MENO	C
MADAWASKA	B	MANTON	B	MATANZAS	B	MCFAIN	C	MENOKEN	C
MADDOCK	A	MANTZ	B	MATAPEAKE	B	MCFAUL	C	MENOMINEE	B
MADDOX		MANU	C	MATAWAN	C	MCGAFFEY	C	MENTO	C
MADELIA	C	MANVEL	C	MATCHER	A	MCGARY	C	MENTOR	B
MADELINE	D	MANWOOD	D	MATFIELD	C	MCGEHEE	C	MEQUON	C
MADERA	D	MANZANITA	C	MATHERS	B	MCGILVERY	D	MERCED	C/D
MADISON	B	MANZANO	C	MATHERTON	B	MCGINTY	B	MERCEDES	D
MADONNA	C	MANZANOLA	C	MATHESON	B	MCGIRK	C	MERCER	C
MADRAS	C	MAPES	C	MATHEWS		MCGOWAN	B	MERCEY	C
MADRID	B	MAPLE MT.	B	MATHISTON	C	MCGRATH	B	MEREDITH	B
MADUREZ	B	MAPLETON	C/D	MATLOCK	D	MCGREW	A	MERETA	C
MAGALLON	B	MARATHON	B	MATMON	D	MCHENRY	B	MERGLE	B
MAGENS	B	MARBLE	A	MATTAPEX	C	MCILWAINE	A	MERIDIAN	B
MAGINNIS	C	MARBLEMOUNT	B	MATTOLE	C	MCINTOSH	B	MERINO	D
MAGNA	D	MARCETTA	A	MAUDE	B	MCINTYRE	B	MERKEL	B
MAGNOLIA	B	MARCUM	B	MAUGHAN	C	MCKAMIE	D	MERLIN	D
MAGNUS	C	MARCUS	C	MAUKEY	C	MCKAY	D	MERMILL	B/D
MAGUAYO	D	MARCY	D	MAUMEE	A/D	MCKENNA	C/D	MERNA	C
MAHAFFY	C/D	MARDEN	C	MAUNABO	D	MCKENZIE	D	MEROS	A
MAHALA	C	MARDIN	C	MAUPIN	C	MCKINLEY	C	MERRIFIELD	B
MAHALASVILLE	B/D	MARENGO	C/D	MAUREPAS	D	MCKINNEY	D	MERRILL	C
MAHANA	B	MARESUA	B	MAURINE	D	MCLAIN	C	MERRILLAN	C
MAHASKA	B	MARGERUM	B	MAURY	B	MCLAURIN	B	MERRIMAC	A
MAHER	C	MARGUERITE	B	MAVERICK	C	MCLEAN	C	MERRITT	B/C
MAHONING	D	MARIA	B/C	MAVIE	D	MCLEOD	B	MER ROUGE	B
MAHUKONA	B	MARIANA	C	MAWAE	A	MCMAHON	C	MERTON	B
MAIDEN	B	MARIAS	D	MAX	B	MCMEEN	C	MERTZ	
MAILE	A	MARICAO	B	MAXEY	C	MCMULLIN	C	MESA	B
MAJADA	B	MARICOPA	B	MAXFIELD	C	MCMURDIE	C	MESCAL	C
MAKAALAE	B	MARIETTA	C	MAXSON	A	MCMURPHY	B	MESCALERO	C
MAKALAPA	D	MARILLA	C	MAXTON	B	MCMURRAY	D	MESITA	C
MAKAPILI	A	MARINA	A	MAXVILLE	A	MCNARY	D	MESKILL	C
MAKAWAO	B	MARION	D	MAXWELL	D	MCPAUL	B	MESMAN	C
MAKAWELI	B	MARIPOSA	C	MAY	B	MCPHERSON	C	MESSER	C
MAKENA	B	MARISSA	C	MAYBERRY	C	MCPHIE	B	MET	D
MAKIKI	B	MARKES	D	MAYBESO	C	MCQUARRIE	D	METALINE	B
MAKOTI	C	MARKEY	D	MAY DAY	D	MCQUEEN	C	METAMORA	B
MAL	B	MARKHAM	C	MAYER	D	MCRAE	B	METEA	B
MALA	B	MARKLAND	C	MAYFIELD	B	MCTAGGART	B	METIGOSHE	A

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METOLIUS	B	MISSION	B	MORGANFIELD	B	NABESNA	C	NESS	D
METRE	D	MITCH	B	MORGNEC		NACEVILLE	C	NESSEL	B
METZ	A	MITCHELL	B	MORIARTY	D	NACHES	B	NESSOPAH	B
MEXICO	D	MITIWANGA	C	MORICAL	C	NACIMIENTO	C	NESTER	C
MHOON	D	MIZPAH	C	MORLEY	C	NACOGDOCHES	B	NESTUCCA	C
MIAMI	B	MOANO	D	MORMON MESA	C	NADEAN	B	NETARTS	A
MIAMIAN	C	MOAPA	D	MOROCCO	A/C	NADINA	B	NETO	B
MICCO	A/D	MOAULA	A	MORONI	D	NAFF	B	NETTLETON	C
MICHELSON	B	MOBEETIE	B	MOROP	C	NAGEESI	B	NEUBERT	B
MICHIGAMME	C	MOCA	D	MORRILL	B	NAGITSY	C	NEUNS	B
MICK	B	MOCHO	B	MORRIS	C	NAGLE	B	NEUSKE	B
MIDAS	D	MODA	D	MORRISON	B	NAHMA	C	NEVADOR	C
MIDDLE	C	MODALE	C	MORROW	C	NAHUNTA	C	NEVILLE	B
MIDDLEBURY	B	MODEL	C	MORSE	D	NAIWA	B	NEVIN	C
MIDESSA	B	MODENA	B	MORTENSON	C	NAKAI	B	NEVINE	B
MIDLAND	D	MODESTO	C	MORTON	B	NAKNEK	D	NEVOYER	D
MIDNIGHT	C	MODOC	C	MORVAL	C	NAMBE	B	NEVTAH	C
MIDVALE	C	MOENKOPIE	D	MOSBY	C	NANAMKIN	A	NEVU	D
MIDWAY	D	MOFFAT	B	MOSCA	A	NANCY	B	NEWARK	C
MIFFLIN	B	MOGOLLON	B	MOSEL	C	NANNY	B	NEWART	B
MIFFLINBURG	B	MOGUL	B	MOSHANNON	B	NANNYTON	B	NEWAYGO	B
MIGUEL	C	MOHAVE	B	MOSHER	D	NANSENE	B	NEWBERG	B
MIKE	D	MOHAVE	B	MOSHERVILLE	C	NANTUCKET	C	NEWBERRY	C
MIKESELL	C	MOHAWK	B	MOSIDA	B	NANUM	C	NEWBY	B
MILACA	B	MOIRA	C	MOSQUET	D	NAPA	C	NEW CAMBRIA	C
MILAN	B	MOKELUMNE	D	MOSSYROCK	B	NAPIER	B	NEW CASTLE	B
MILES	B	MOKENA	C	MOTA	B	NAPLES	B	NEWCOMB	A
MILFORD	C	MOKULEIA	B	MOTTSVILLE	A	NAPPANEE	D	NEWDALE	B
MILHAM	C	MOLAND	B	MOULTON	B	NAPTOWNE	B	NEWELL	B
MILHEIM	C	MOLCAL	B	MOUND	C	NARANJITO	C	NEWELLTON	D
MILL	B	MOLENA	A	MOUNTAINBURG	D	NARANJO	C	NEWFANE	
MILLARD	B	MOLINOS	B	MOUNTAINVIEW	B/D	NARCISSE	B	NEWFORK	D
MILLBORO	D	MOLLY	B	MOUNTAINVILLE	B	NARD	B	NEWKIRK	B
MILLBROOK	B	MOLOKAI	B	MOUNT AIRY	A	NARLON	C	NEWLANDS	B
MILLBURNE	B	MOLSON	B	MOUNT CARROLL	B	NARON	B	NEWLIN	B
MILLCREEK	B	MOLYNEUX	B	MOUNT HOPE	B	NARRAGANSETT	B	NEWMARKET	B
MILLER	D	MONAD	A	MOUNT HOOD	B	NARROWS	D	NEWPORT	C
MILLERLUX	D	MONAHAN	C	MOUNT LUCAS	C	NASER	B	NEWRY	B
MILLERTON	D	MONAHANS	B	MOUNT OLIVE	D	NASH	B	NEWSKAH	B
MILLETT	B	MONARDA	D	MOUNTVIEW	B	NASHUA	A	NEWSTEAD	D
MILLGROVE	B/D	MONCLOVA	B	MOVILLE	C	NASHVILLE	B	NEWTON	A/D
MILL HOLLOW	B	MONDAMIN	C	MOWATA	D	NASON	C	NEWTONIA	B
MILLICH	D	MONDOVI	B	MOWER	C	NASSAU	C/D	NEWTOWN	C
MILLINGTON	B	MONEE	D	MOYINA	D	NASSET	B	NEWVILLE	C
MILLIS	C	MONICO	B	MUCARA	D	NATALIE	C	NEZ PERCE	C
MILLRACE	B	MONIDA	B	MUCET	C	NATCHEZ	B	NIAGARA	C
MILLSAP	C	MONITEAU	D	MUDRAY	D	NATHROP	B	NIART	B
MILLSDALE	B/D	MONMOUTH	C	MUD SPRINGS	C	NATIONAL	B	NIBLEY	C
MILLSHOLM	C	MONO	D	MUGHOUSE	C	NATRONA	B	NICHOLSON	C
MILLVILLE	B	MONOLITH	C	MUIR	B	NATURITA	B	NICHOLVILLE	C
MILLWOOD	D	MONONA	B	MUIRKIRK	B	NAUKATI	D	NICKEL	B
MILNER	C	MONONGAHELA	C	MUKILTEO	D	NAUMBURG	C	NICKLE	B
MILPITAS	C	MONROE	B	MULDROW	D	NAVAJO	D	NICODEMUS	B
MILROY	D	MONROEVILLE	C/D	MULKEY	C	NAVAN	D	NICOLAUS	C
MILTON	C	MONSE	B	MULLINS	D	NAVARCO	B	NICOLLET	B
MIMBRES	C	MONSERATE	C	MULT	C	NAVESINK		NIELSEN	D
MIMOSA	C	MONTAGUE	D	MULTORPOR	A	NAYLOR		NIGHTHAWK	B
MINAM	B	MONTALTO	C	MUMFORD	B	NAZ	B	NIHILL	B
MINATARE	D	MONTARA	D	MUNDELEIN	B	NEAPOLIS	B/D	NIKISHKA	B
MINCHEY	B	MONTAUK	C	MUNISING	B	NEBEKER	C	NIKLASON	B
MINCO	B	MONTCALM	A	MUNK	C	NEBISH	B	NIKOLAI	D
MINDALE	B	MONTE CRISTO	D	MUNSON	D	NEBO		NILAND	C
MINDEGO	B	MONTEGRANDE	D	MUNUSCONG	D	NECHE	C	NILES	C
MINDEMAN	B	MONTELL	D	MURDO	B	NEDERLAND	B	NIMROD	C
MINDEN	C	MONTELLO	C	MURDOCK	C	NEEDHAM	D	NINCH	C
MINE	B	MONTEVALLO	D	MUREN	B	NEEDLE PEAK	C	NINEMILE	D
MINEOLA		MONTGOMERY	D	MURRILL	B	NEEDMORE	C	NINEVEH	B
MINER	D	MONTICELLO	B	MUSCATINE	B	NEELEY	B	NINIGRET	B
MINERAL	A	MONTIETH	A	MUSE	C	NEGITA	B	NININGER	B
MINERAL MT.	C	MONTMORENCI	B	MUSELLA	B	NEGLEY	B	NINNESCAH	B
MINERVA	B	MONTOSA	C	MUSICK	B	NEHALEM	B	NIOBELL	C
MING	B	MONTOUR	D	MUSINIA	B	NEILTON	A	NIOTA	D
MINGO	B	MONTOYA	C	MUSKINGUM	C	NEISSON	B	NIPE	B
MINIDOKA	C	MONTPELLIER	C	MUSKOGEE	C	NEKIA	C	NIPPERSINK	B
MINNEISKA	C	MONTROSE	B	MUSSELSHELL	B	NELLIS	B	NIPSUM	C
MINNEOSA	A	MONTVALE	D	MUSSEY	D	NELSCOTT	B	NIRA	B
MINNEQUA	B	MONTVERDE	A/D	MUSTANG	A/D	NELSON	B	NISHNA	C
MINNETONKA	D	MONTWELL	C	MUTNALA	B	NEMAH	C	NISHON	D
MINNEWAUKAN	B	MOODY	B	MUTUAL	B	NENANA	B	NISQUALLY	A
MINNIECE	D	MOOHOO	B	MYAKKA	A/D	NENNO	B	NISSWA	B
MINOA	C	MOOSE RIVER	C	MYATT	B/D	NEOLA	D	NIU	B
MINORA	C	MOPA	B	MYERS	D	NEOTOMA	B	NIULII	C
MINTO	B	MORADO	C	MYERSVILLE	B	NEPESTA	C	NIVLOC	C
MINU	D	MORALES	C	MYLREA	B	NEPHI	B	NIWOT	C
MINVALE	B	MORO	C	MYRICK	D	NEPPEL	B	NIXA	C
MIRABAL	C	MOREAU	C	MYRTLE	B	NEPTUNE	A	NIXON	B
MIRACLE	B	MOREHEAD	C	MYSTEN	A	NERESON	B	NIXONTON	B
MIRAMAR	B	MOREHOUSE	C	MYSTIC	D	NESDA	A	NIZIAN	A
MIRANDA	D	MORELAND	D	MYTON	B	NESHAMINY	B	NOBLE	B
MIRES	B	MORELANDTON	A			NESIKA	B	NOBSCOTT	A
MIRROR	B	MOREY	D	N-BAR	B	NESKOWIN	B	NODAWAY	B
MIRROR LAKE	A	MORFITT	B	NAALEHU	B	NESPELEM	B	NOEL	D

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NOHILI	D	OCILLA	C	ONSLOW	B	OWOSSO	B	PARALOMA	C
NOKASIPPI	D	OCKLEY	B	ONTARIO	B	OWYHEE	B	PARAMORE	D
NOKAY	C	OCOEE	A/D	ONTKO	B/D	OXALIS	C	PARASOL	B
NOKOMIS	B	OCONEE	C	ONTONAGON	D	OXBOW	C	PARCELAS	D
NOLAM	B	OCONTO	B	ONYX	B	OXERINE	C	PARDEE	D
NOLICHUCKY	B	OCOSTA	C	OOKALA	A	OXFORD	D	PAREHAT	B
NOLIN	B	OCQUEOC	B	OPAL	D	OZAMIS	B/D	PARENT	C
NOLO	B	OCTAGON	B	OPEQUON	C/D	OZAN	D	PARIETTE	C
NOME	C	ODELL	B	OPHIR	C	OZAUKEE	C	PARIS	
NONDALTON	B	ODERMOTT	C	OPIHIKAO	D			PARISHVILLE	C
NONOPAHU	D	ODESSA	D	OQUAGA	C	PAAIKI	B	PARKAY	B
NOOKACHAMPS	C/D	ODIN	C	ORA	C	PAALOA	B	PARKDALE	B
NOOKSACK	B	ODNE	C	ORAN	B	PAAUHAU	A	PARKE	B
NOONAN	D	O'FALLON	D	ORANGE	D	PACHAPPA	B	PARKER	B
NORA	B	OGDEN	D	ORANGEBURG	B	PACHECO	B/C	PARKFIELD	C
NORAD	B	OGEECHEE	C	ORCAS	D	PACK	C	PARKHILL	D
NORBORNE	B	OGEMAW	C	ORCHARD	B	PACKARD	B	PARKHURST	
NORBY	B	OGILVIE	C	ORD	A	PACKER	C	PARKINSON	B
NORD	B	OGLALA	B	ORDNANCE	C	PACKHAM	B	PARKVILLE	C
NORDEN	B	OGLE	B	ORDWAY	D	PACKSADDLE	B	PARKWOOD	A/D
NORDNESS	B	OHAYSI	C	ORELIA	D	PACKWOOD	D	PARLEYS	B
NORFOLK	B	OHIA	A	ORELLA	D	PACOLET	B	PARLIN	C
NORGE	B	OJAI	B	OREM	A	PACTOLUS	C	PARLO	B
NORKA	B	OJATA	D	ORESTIMBA	C	PADEN	C	PARMA	C
NORMA	B	OKANOGAN	B	ORFORD	C	PADRONI	B	PARNELL	D
NORREST	C	OKAW	D	ORIDIA	C	PADUCAH	B	PARR	B
NORRIS	C	OKEECHOBEE	A/D	ORIF	A	PADUS	B	PARRAN	D
NORTHDALE	C	OKEELANTA	A/D	ORIO	C	PAESL	B	PARRISH	C
NORTHFIELD	B	OKEMAH	C	ORION	B	PAGET	B	PARSHALL	B
NORTHPORT		OKLARED	B	ORITA	B	PAGODA	C	PARSIPPANY	D
NORTH POWDER	C	OKLAWAHA	A/D	ORLAND	B	PAHRANAGAT	C	PARSONS	D
NORTHUMBERLAND	C/D	OKMOK	C	ORLANDO	A	PAHREAH	D	PARTRI	C
NORTON	C	OKO	D	ORMAN	C	PAHROC	D	PASAGZHAK	B
NORTONVILLE	C	OKOBOJI	C	ORMSBY	B/C	PAIA	C	PASCO	B
NORTUNE	D	OKOLONA	D	ORODELL	C	PAICE	C	PASO SECO	D
NORWALK	B	OKREEK	D	OROFINO	B	PAINESVILLE		PASQUETTI	C/D
NORWAY FLAT	A	OKTIBBEHA	D	ORO GRANDE	C	PAINTROCK	B	PASQUOTANK	B/D
NORWELL	C	OLA	C	ORONO	D	PAIT	B	PASSAR	C
NORWICH	D	OLAA	A	OROVADA	C	PAJARITO	B	PASS CANYON	D
NORWOOD	B	OLALLA	C	ORR	C	PAJARO	C	PASSCREEK	B
NOTI	D	OLANTA	B	ORRVILLE	C	PAKALA	B	PASTURA	D
NOTUS	A	OLATHE	C	ORSA	A	PAKINI	B	PATAHS	B
NOVARA	B	OLD CAMP	C	ORSINO	A	PALA	B	PATENT	C
NOVARY	B	OLDHAM	C	ORTELLO	A	PALACIO	B	PATILLAS	B
NOWOOD	C	OLDS	C	ORTIGALITA	C	PALAPALAI	B	PATILO	C
NOYO	C	OLDSMAR	B/D	ORTING	C	PALATINE	B	PATIT CREEK	B
NUBY	C	OLDWICK	B	ORTIZ	C	PALESTINE	B	PATNA	C
NUCKOLLS	C	OLELO	B	ORWOOD	B	PALISADE	B	PATOUTVILLE	C
NUCLA	B	OLENA	B	OSAGE	D	PALMA	B	PATRICIA	B
NUECES	C	OLEQUA	B	OSAKIS	B	PALMAREJO	C	PATRICK	B
NUGGET	C	OLETE	B	OSGOOD	B	PALM BEACH	A	PATROLE	C
NUMA	C	OLEX	B	OSHA	B	PALMER	D	PATTANI	D
NUNDA	C	OLGA	C	OSHAWA	D	PALMER CANYON	B	PATTENBURG	B
NUNICA	C	OLI	B	O'SHEA	C	PALMICH	B	PATTERSON	C
NUNN	C	OLIAGA	B	OSHKOSH	C	PALMS	D	PATTON	B/C
NUSS	D	OLINDA	B	OSHTEMO	B	PALMYRA	B	PATWAY	C
NUTLEY	C	OLIPHANT	B	OSIER	B/D	PALO	B	PAUL	B
NUTRAS	C	OLIVENHAIN	C	OSKA	C	PALOMAS	B	PAULDING	D
NUTRIOSO	B	OLIVER	B	OSMUND	B	PALOMINO	D	PAULINA	D
NUVALDE	C	OLIVIER	C	OSO	B	PALOS VERDES	B	PAULSELL	D
NYALA	D	OLMITO	D	OSCBB	D	PALOUSE	B	PAULVILLE	B
NYMORE	A	OLMITZ	B	OSCRIDGE	C	PALSGROVE	B	PAUMALU	B
NYSSA	C	OLMOS	C	OSCTE	B	PAMLICO	D	PAUNSAUGUNT	D
NYSSATON	B	OLMSTED	B/D	OSSIAN	C	PANOA	C	PAUSANT	B
NYSTROM	C	OLNEY	B	OST	B	PAMSDEL	D	PAUWELA	B
		OLOKUI	D	OSTRANDER	B	PANA	B	PAVAHROO	B
OAHE	B	OLPE	C	OTERO	B	PANACA	D	PAVANT	D
OAKDALE	B	OLSON	C	OTHELLO	D	PANAEWA	D	PAVILLION	B
OAKDEN	D	OLTON	C	OTIS	C	PANASOFFKEE	D	PAWCATUCK	D
OAKFORD	B	OLUSTEE	B/D	OTISCO	A	PANCHERI	B	PAWLET	B
OAK GLEN	B	OLYIC	B	OTISVILLE	A	PANCHUELA	C	PAWNEE	D
OAK GROVE	C	OLYMPIC	B	OTLEY	B	PANCO	B	PAXTON	C
OAK LAKE	B	OMAHA	B	OTSEGO	C	PANDOAH	C	PAYETTE	B
OAKLAND	C	OMAK	C	OTTER	B/D	PANDORA	D	PAYMASTER	B
OAKS RIDGE	C	OMEGA	A	OTTERBEIN	C	PANDURA	D	PAYNE	C
OAKVILLE	A	OMENA	B	OTTERHOLT	B	PANE	B	PAYSON	D
OAKWOOD	D	OMNI	C	OTTOKEE	A	PANGUITCH	B	PEACHAM	D
OANAPUKA	B	ONA	A/D	OTWAY	D	PANHILL	B	PEARL HARBOR	D
OASIS	B	ONALASKA	B	OTWELL	C	PANIOGUE	B	PEARMAN	
OATMAN	B	ONAMIA	B	OUACHITA	C	PANKY	C	PEARSOLL	D
OBAN	C	ONARGA	B	OURAY	A	PANOCHE	B	PEAVINE	C
OBARO	B	ONAWA	D	OUTLET	C	PANOLA	D	PECATONICA	B
OBRAY	D	ONAWAY	B	OVALL	C	PANSEY	D	PECOS	C
OBURN	D	ONDAWA	B	OVERGAARD	C	PANTHER	C	PEDEE	C
OCALA	D	ONEIDA	B	OVERLY	C	PANTON	C	PEDERNALES	C
OCEANET	D	O'NEILL	B	OVERTON	D	PAOLA	A	PEDIGO	B/C
OCEANO	A	ONEONTA	B	OVID	C	PAOLI	B	PEDLAR	D
OCHEYEDAN	B	ONITA	C	OVINA	B	PAPAA	D	PEDRICK	B
OCHLOCKONEE	B	ONITE	B	OWEGO	D	PAPAI	A	PEEBLES	C
OCHO	D	ONOTA	C	OWEN CREEK	C	PAPAKATING	D	PEEL	C
OCHOCO	C	ONOVA	D	OWENS	D	PAPOOSE	C	PEELER	B
OCHOPEE	B/D	ONKAY	D	OWHI	B	PARADISE	C	PEEVER	C

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PEGLER	D	PIE CREEK	D	POE	B/C	PREBLE	C	QUINN	D
PEGRAM	B	PIERIAN	A	POGANEAB	C	PRENTISS	C	QUINNEY	C
PEKIN	C	PIERPONT	C	POGUE	B	PRESQUE ISLE	B	QUINTON	
PELHAM	B/D	PIERRE	D	POHAKUPU	A	PRESTO	A	QUITMAN	C
PELIC	C	PIIHONUA	A	POINSETT	B	PRESTON	A	QUONSET	A
PELLA	D	PIKE	B	POINT	B	PREWITT	C		
PELONA	C	PILCHUCK	A	POINT ISABEL	C	PREY	D	RABER	C
PEMBERTON	A	PILGRIM	B	POJOAQUE	B	PRICE	C	RABEY	A
PEMBINA	C	PILOT	B	POKEGEMA	B	PRIDA	D	RABIDEUX	B
PEMBROKE	B	PILOT ROCK	C	POKER	B	PRIDHAM	D	RABUN	B
PENA	B	PIMA	B	POLAND		PRIETA	C	RACE	D
PENCE	A	PINAL	D	POLAR	B	PRIMEAUX	C	RACHERT	D
PENDEN	B	PINALENO	B	POLATIS	C	PRIMGHAR	B	RACINE	B
PEND OREILLE	B	PINATA	C	POLE	A	PRINCETON	B	RACCON	D
PENDROY	D	PINAVETES	A	POLEBAR	C	PRINEVILLE	C	RAD	C
PENISTAJA	B	PINCHER	C	POLELINE	B	PRING	B	RADFORD	B
PENITENTE	B	PINCKNEY	C	POLEO	C	PRINS	C	RADLEY	C
PENN	C	PINCONNING	D	POLEY	C	PROCTOR	B	RADNOR	D
PENNEL	C	PINCUSHION	B	POLICH	C	PROGRESSO	C	RAFAEL	D
PENNINGTON	B	PINEDA	B/D	POLLARD	C	PROMISE	D	RAGLAN	D
PENNISULA	C	PINEDALE	B	POLLASKY	C	PROMO	D	RAGNAR	B
PENO	C	PINEGUEST	B	POLLY	B	PROMONTORY	B	RAGO	C
PENOVER	C	PINELLOS	A/D	POLO	B	PRONG	C	RAGSDALE	B/D
PENROSE	D	PINETOP	C	POLSON	C	PROSPECT	B	RAGTOWN	D
PENTHOUSE	D	PINEVILLE	B	POLVADERA	C	PROSPER	B	RAHM	C
PENTZ	D	PINEY	C	POMAT	C	PROSSER	C	RAIL	C/D
PENWOOD	A	PINICON	B	POMELLO	C	PROTIVIN	C	RAINBOW	C
PEOGA	C	PINKEL	C	POMPANO	A/D	PROUT	C	RAINEY	B
PEOH	C	PINKSTON	B	POMPONIC	C	PROVIDENCE	C	RAINS	B/D
PEONE	B/C	PINNACLES	C	POMPTON	B	PROVO	C	RAINSBORO	C
PEOTONE	C	PINO	C	POMROY	B	PROVO BAY	D	RAKE	D
PEPOON	B	PINOLA	C	PONCENA	D	PROWERS	B	RALSEN	B/C
PEQUEA	C	PINOLE	B	PONCHA	A	PTARMIGAN	B	RAMADA	C
PERCHAS	D	PINON	C	POND	B/C	PUAULU	A	RAMADERO	B
PERCIVAL	C	PINONES	D	POND CREEK	B	PUCHYAN	A	RAMBLER	B
PERELLA	C	PINTAS	D	PONDILLA	A	PUDDLE	D	RAMELLI	C
PERHAM	C	PINTLAR	A	PONIL	D	PUERCO	D	RAMIRES	D
PERICO	B	PINTO	C	PONTOTOC	B	PUETT	C	RAMMEL	C
PERKINS	C	PINTURA	A	PONZER	D	PUGET	C	RAMO	C
PERKS	A	PINTWATER	C	POOKU	A	PUGSLEY	B	RAMONA	B
PERLA	C	PIOPOLIS	D	POOLE	B/D	PUHI	A	RAMPART	B
PERMA	A	PIPER	B/C	POOLER	D	PUHIMAU	D	RAMPARTAR	A
PERMANENTE	C	PIROUETTE	C	POORMA	B	PULASKI	B	RAMSEY	D
PERRIN	B	PISGAH	C	POPE	B	PULEHU	B	RAMSHORN	B
PERRINE	D	PISHKUN	B	POPPLETON	A	PULLMAN	D	RANCE	C
PERROT	D	PISTAKEE	B	POQUONOCK	C	PULS	D	RANCHERIA	B
PERRY	D	PIT	D	PORRETT	B/D	PULSIPHER	D	RAND	B
PERRYVILLE	B	PITTMAN	D	PORT	B	PULTNEY	C	RANDADO	C
PERSAYO	D	PITTSFIELD	B	PORTAGEVILLE	D	PUMPER	C	RANDALL	D
PERSHING	C	PITTSTOWN	C	PORTALES	C	PUNA	A	RANDOLPH	D
PERSIS	B	PITTWOOD	B	PORT BYRON	B	PUNALUU	D	RANDS	C
PERT	D	PLACENTIA	C	PORTERS	B	PUNOHU	A	RANGER	D
PERU	C	PLACERITOS	C	PORTERVILLE	D	PURDAM	C	RANIER	C
PESCADERO	C/D	PLACID	A/D	PORTHILL	C	PURDY	D	RANKIN	C
PESET	C	PLACK	D	PORTINO	C	PURGATORY	D	RANTOUL	D
PESHASTIN	B	PLAINFIELD	A	PORTLAND	D	PURNER	D	RANYHAN	B
PESO	C	PLAINVIEW	C	PORTNEUF	B	PURSLEY	B	RAPELJE	C
PETEETNEET	D	PLAISTED	C	PORTOLA	C	PURVES	D	RAPHO	B
PETERBORO	B	PLANO	B	PORTSMOUTH	D	PUSTOI	A	RAPIDAN	B
PETERS	D	PLATA	B	POSANT	C	PUTNAM	D	RARDEN	C
PETOSKEY		PLATEA	C	POSEY	B	PUUKALA	D	RARICK	B
PETRIE	D	PLATEAU	B	POSITAS	D	PUUONE	C	RARITAN	C
PETROLIA	D	PLATNER	C	POSKIN	C	PUU OO	A	RASBAND	B
PETTONS	C	PLATO	C	POSOS	C	PUU OPAE	B	RASSET	B
PEWAMO	B/D	PLATTE	C	POST	D	PUU PA	B	RATHBUN	C
PEYTON	B	PLATTVILLE	B	POTAMO	D	PUYALLUP	B	RATLIFF	B
PHAGE	B	PLAZA	B/C	POTLATCH	C	PYLE	A	RATON	C
PHARO	B	PLEASANT	C	POTRATZ	C	PYLON	C	RATTLER	B
PHAROLID	D	PLEASANT GROVE	B	POTSDAM	C	PYOTE	A	RAUB	B
PHEBA	C	PLEASANTON	B	POTTER	C	PYRAMID	C	RAUVILLE	D
PHEENEY	B	PLEASANT VALE	B	POTTER	C	PYRMONT	D	RAUZI	B
PHELAN	B	PLEASANT VIEW	B	POTTS	B			RAVALLI	C
PHELPS	B	PLEDGER	D	POUCRE	B	QUAKER	C	RAVENDALE	D
PHIFERSON	B	PLEEK	C	POULTNEY	B	QUAKERTOWN	B	RAVENNA	C
PHILSON	B/D	PLEINE	C	POVERTY	A	QUAMBA	D	RAVOLA	B
PHILLIPS	C	PLEVNA	D	POWDER	B	QUANAH	B	RAWAH	B
PHILLIPSBURG	A	PLOME	C	POWDERHORN	C	QUANDAHL	B	RAWHIDE	D
PHILO	B	PLOVER	B	POWELL	C	QUARLES	D	RAWSON	B
PHILOMATH	D	PLUMAS	B	POWER	B	QUARTZBURG	C	RAY	B
PHIPPS	C	PLUMMER	B/D	POWHITE	C	QUATAMA	C	RAYADO	C
PHOEBE	B	PLUSH	B	POWLEY	D	QUAY	C	RAYENOUF	B
PHOENIX	D	PLUTH	B	POWWATKA	C	QUEBRADA	C	RAYMONDVILLE	D
PIASA	D	PLUTOS	C	POY	D	QUEETS	B	RAYNE	B
PICACHO	C	PLYMOUTH	A	POYGAN	D	QUEMADO	C	RAYNESFORD	B
PICAYUNE	B	POALL	C	POZO	C/D	QUENZER	D	RAYNHAM	C
PICKAWAY	C	POARCH	B	POZO BLANCO	B	QUICKSELL	C	RAYNOR	D
PICKENS	D	POCALLA	A	PRAG	C	QUIGLEY	B	RAZOR	C
PICKETT	B	POCATELLO	B	PRATHER	B	QUILCENE	C	RAZORT	B
PICKFORD	D	POCKER	D	PRATLEY	C	QUILLAYUTE	B	READING	C
PICKWICK	B	POCOMOKE	C	PRATT	A	QUIMBY	C	READINGTON	C
PICO	B	PODO	D	PREACHER	B	QUINCY	A	READLYN	B
PICTOU	B	PODUNK	B	PREBISH	D	QUINLAN	C	REAGAN	B

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REAKOR	B	RHOADES	D	ROCK RIVER	B	RUDYARD	D	SALMON	B
REAL	D	RIB	C	ROCKTON	B	RUELLA	B	SALOL	D
REAP	D	RICCO	D	ROCKWELL	B	RUGGLES	B	SALONIE	B
REARDAN	C	RICETON	B	ROCKWOOD	B	RUIDOSO	C	SALTAIR	D
REAVILLE	C	RICEVILLE	C	ROCKY FORD	B	RUKO	D	SALT CHUCK	A
REBA	C	RICHARDSON	B	RODDY		RULE	B	SALTER	B
REBEL	B	RICHEAU	D	RODMAN	A	RULICK	C	SALTERY	D
REBUCK		RICHEY	C	ROE		RUMBO	C	SALT LAKE	D
RECLUSE	D	RICHFIELD	C	ROEBUCK	D	RUMFORD	B	SALUDA	C
REDBANK	B	RICHFORD	A	ROELLEN	D	RUMNEY	C	SALUVIA	
RED BAY	B	RICHLIE	A	ROESIGER	B	RUMPLE	C	SALVISA	C
RED BLUFF	B	RICHMOND	D	ROHNERVILLE	B	RUM RIVER	C	SALZER	D
RED BUTTE	B	RICHTER	B	ROHRERSVILLE	C	RUNE	C	SAMBA	D
REDBY	C	RICHVALE	B	ROKEBY	D	RUNNELLS	C	SAMISH	C/D
REDCHIEF	C	RICHVIEW	C	ROLETTE	C	RUNNYMEDE	B	SAMMAMISH	C
REDCLOUD	B	RICHWOOD	B	ROLFE	C	RUPERT	A	SAMPSEL	D
REDDICK	C	RICKMORE	C	ROLISS	D	RUSCO	C	SAMPSON	B
REDDING	D	RICKS	A	ROLLA	C	RUSE	D	SANSIL	D
REDFIELD	B	RICREST	B	ROLLIN	D	RUSH	C	SAN ANDREAS	C
RED HILL	C	RIDD	C	ROLOFF	C	RUSHTOWN	A	SAN ANTON	B
RED HOOK	C	RIDGEBURY	C	ROMBO	C	RUSHVILLE	C	SAN ANTONIO	C
REDLAKE	D	RIDGECREST	C	ROMEO	C	RUSS	B	SAN ARCACIO	B
REDLANDS	B	RIDGEDALE	B	ROMNEY	C	RUSSELL	B	SAN BENITO	B
REDMANSON	B	RIDGELAND	D	ROMULUS	D	RUSSELLVILLE	C	SANCHEZ	D
REDMOND	C	RIDGELAWN	A	ROND	D	RUSSLER	C	SANDALL	C
REDNUN	C	RIDGELY	B	RONNEBY	B	RUSTON	B	SANDERSON	B
REDOLA	B	RIDGEVILLE	B	RONSON	B	RUTLAND	C	SANDLAKE	D
REDONA	B	RIDGEWAY	D	ROSACHI	C	RUTLEGE	D	SANDLEE	A
REDRIDGE	B	RIETBROCK	C	ROSAMOND	B	RYAN	D	SANELI	D
REDROB	B	RIFFE	B	ROSANE	C	RYAN PARK	B	SAN EMIGDIO	B
RED ROCK	B	RIFLE	A/D	ROSARIO	C	RYDE	B/D	SANGER	B
RED SPUR	B	RIGA	D	ROSCOE	D	RYDER	C	SAN GERMAN	D
REDSTOE	B	RIGGINS	A	ROSCOMMON	D	RYEGATE	B	SANGO	C
REDTHAYNE	B	RILEY	C	ROSEBERRY	B	RYEPATCH	D	SANGREY	A
REDTOM	C	RILLA	B	ROSEBLOOM	D	RYER	C	SANILAC	C
REDVALE	C	RILLITO	B	ROSEBUD	B	RYUS	C	SAN ISABEL	B
REDVIEW	C	RIMER	C	ROSEBURG	B			SAN JOAQUIN	D
REE	B	RIMINI	A	ROSE CREEK	C	SABANA	D	SAN JON	C
REED	C	RIMROCK	D	ROSEGLEN	B	SABANA SECA	D	SAN JOSE	B
REEDER	B	RIN	B	ROSEHILL	D	SABENYO	B	SAN JUAN	A
REEDPOINT	C	RINCON	C	ROSELAND	D	SABINA	C	SAN LUIS	B
REEDY	C	RINCONADA	C	ROSELMS	D	SABINE	A	SAN MATEO	C
REELFOOT	C	RINGLING	C	ROSEMOUNT	B	SABLE	D	SAN MIGUEL	C
REESER	C	RINGO	D	ROSENDALE	B	SAC	B	SANPETE	A
REESVILLE	C	RINGOLD	B	ROSEVILLE	B	SACO	D	SANPITCH	C
REFUGE	C	RINGWOOD	B	ROSEWORTH	C	SACRAMENTO	C/D	SAN POIL	B
REGAN	B	RIO	D	ROSHE SPRINGS	C	SACUL	D	SAN SABA	D
REGENT	C	RIO ARRIBA	D	ROSITAS	A	SADDLE	B	SAN SEBASTIAN	B
REHM	C	RIO GRANDE	B	ROSLYN	B	SADDLEBACK	B	SANTA	C
REICHEL	B	RIO KING	C	ROSMAN	B	SADIE	B	SANTA CLARA	C
REIFF	B	RIO LAJAS	A	ROSNEY	C	SADLER	C	SANTA FE	D
REILLY	A	RIO PIEDRAS	B	ROSS	B	SAFFELL	B	SANTA ISABEL	D
REINACH	B	RIPLEY	B	ROSS FORK	C	SAGANING	D	SANTA LUCIA	C
RELAN	A	RIPON	B	ROSSI	C	SAGE	D	SANTA MARTA	C
RELAY	B	RIRIE	B	ROSSMOYNE	C	SAGEHILL	B	SANTANA	C
RELIANCE	C	RISTA	C	ROSS VALLEY	C	SAGEMOOR	C	SANTAQUIN	A
RELIZ	D	RISUE	D	ROTAN	C	SAGERTON	C	SANTA YNEZ	C
RELSE	B	RITCHEY	B	ROTHIEMAY	B	SAGINAW		SANTEE	D
REMBERT	D	RITNER	C	ROTHSAY	B	SAGO	D	SANTIAGO	B
REMMIT	A	RITTER	B	ROUBIDEAU	C	SAGOUSPE	C	SANTIAM	C
REMSEN	D	RITTMAN	C	ROUEN	C	SAGUACHE	A	SAN TIMOTEO	C
REMUDAR	B	RITZCAL	B	ROUND BUTTE	D	SAHALI	B	SANTONI	D
REMUNDA	C	RITZVILLE	B	ROUNDTOP	D	SAINT ALBANS	B	SANTOS	C
RENFROW	D	RIVERHEAD	B	ROUNDUP	C	SAINT CHARLES	B	SANTO TOMAS	B
RENO	D	RIVERSIDE	A	ROUNDY	C	SAINT CLAIR	D	SAN YSIDRO	D
RENOHILL	C	RIVERTON	B	ROUSSEAU	A	SAINT ELMO	A	SAPP	D
RENOVA	B	RIVERVIEW	B	ROUTON	D	SAINT GEORGE	C	SAPPHIRE	B
RENOX	B	RIVRA	A	ROUTT	C	SAINT HELENS	A	SAPPINGTON	B
RENSHAW	B	RIXIE	C	ROVAL	D	SAINT IGNACE	C	SARA	C
RENSLOW	B	RIZ	D	ROWE	D	SAINT JOE	B	SARALEGUI	B
RENSSELAER	C	ROANOKE	C	ROWENA	D	SAINT JOHNS	B/D	SARANAC	D
RENTIDE	C	ROBBINS	B	ROWLAND	C	SAINT LUCIE	A	SARAPH	D
RENTON	B/C	ROBBS	D	ROWLEY	B	SAINT MARTIN	C	SARATOGA	B
RENTSAC	C	ROBERTS	D	ROXBURY	B	SAINT MARYS	B	SARCO	B
REPARADA	D	ROBERTSDALE	C	ROY	B	SAINT NICHOLAS	C	SARDINIA	C
REPPART	B	ROBERTSVILLE	D	ROYAL	B	SAINT PAUL	B	SARGEANT	D
REPUBLIC	B	ROBIN	B	ROYALTON	C	SAINT THOMAS	D	SARITA	A
RESCUE	C	ROBINSON	D	ROYSTONE	B	SALADO	B	SARKAR	D
RESERVE	B	ROBINSONVILLE	B	ROZA	D	SALAL	B	SARPY	A
RESNER	B	ROBLEDO	D	ROZELLVILLE	B	SALAMATOF	C	SARTELL	A
RET	B/C	ROB ROY	C	ROZETTA	B	SALAS	C	SASKA	B
RETRIEVER	D	ROBY	C	ROZLEE	C	SALCHAKET	B	SASSAFRAS	B
RETSOF	C	ROCHE	C	RUARK	C	SALEM	B	SASSER	B
RETSOK	B	ROCHELLE	C	RUBICON	A	SALEMSBURG	B	SATANKA	C
REXBURG	B	ROCHEPORT	C	RUBIO	C	SALGA	C	SATANTA	B
REXOR	A	ROCKAWAY	C	RUBY	B	SALIDA	A	SATELLITE	C
REYES	C/D	ROCKCASTLE	D	RUCH	B	SALINAS	C	SATT	D
REYNOLDS		ROCK CREEK	D	RUCKLES	D	SALISBURY	D	SATTLEY	B
REYNOSA	B	ROCKFORD	B	RUCLICK	C	SALIX	B	SATTRE	B
REYWAT	D	ROCKINGHAM	C/D	RUDD	D	SALKUM	C	SATUS	B
RHAME	B	ROCKLIN	C	RUDEEN	B	SALLISAW	B	SAUCE	B
RHINEBECK	D	ROCKPORT		RUDOLPH	C	SALLYANN	C	SAUGATUCK	C

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January, 1971

EXHIBIT 2-1

SAUGUS	B
SAUK	B
SAULICH	D
SAUM	C
SAUNDERS	C
SAUVIE	C/D
SAUVOLA	C
SAVAGE	C
SAVANNAH	C
SAVO	C
SAVOIA	B
SAWABE	D
SAWATCH	C
SAWCREEK	B
SAWMILL	C
SAWYER	C
SAXBY	D
SAXON	B
SAYBROOK	B
SAYLESVILLE	C
SAYLOR	A
SCALA	B
SCAMMAN	C
SCANDIA	B
SCANTIC	C
SCAR	A
SCARBORO	D
SCAVE	C
SCHAFFENAKER	A
SCHAMBER	A
SCHAMP	C
SCHAPVILLE	C
SCHEBLY	D
SCHERRARD	D
SCHLEY	B
SCHNORBUSH	C
SCHODACK	
SCHODSON	C
SCHOFIELD	B
SCHOHARIE	C
SCHOLLE	C
SCHOOLEY	C/D
SCHRIER	B
SCHROOK	B
SCHUMACHER	B
SCHUYLKILL	B
SCIO	B
SCIOTOVILLE	C
SCISM	B
SCITUATE	C
SCOBEY	C
SCOOTENEY	B
SCORUP	C
SCOTT	D
SCOTT LAKE	B
SCOUT	A
SCOWLALE	C
SCRANTON	B/D
SCRIBA	C
SCRIVER	B
SCROGGIN	C
SCULLIN	C
SEABROOK	A
SEAMAN	C
SEAQUEST	C
SEARCHLIGHT	C
SEARING	B
SEARLA	B
SEARLES	C
SEATON	B
SEATTLE	D
SEBAGO	D
SEBASTIAN	D
SEBASTOPOL	C
SEBEKA	D
SEBEWA	B/D
SEBREE	D
SEBRING	D
SECATA	C
SECRET	C
SECRET CREEK	B
SEDAN	
SEEDSKADEE	D
SEFS	C
SEEWEE	B
SEGAL	D
SEGNO	C
SEHORN	D
SEJITA	D
SEKIU	D
SELAH	C
SELDEN	C
SELFRIDGE	C
SELKIRK	D
SELLE	B
SELLERS	A/D
SELMA	B
SEMIAHMOO	C
SEMIHMOO	D
SEMINARIO	D
SEN	B
SENECAVILLE	C
SEQUATCHIE	B
SEQUIM	A
SEQUOIA	C
SERENE	D
SERNA	D
SEROCO	A
SERPA	C/D
SERVOSS	D
SESAME	C
SESPE	C
SESSIONS	C
SESSUM	D
SETTERS	C
SETTLEMEYER	D
SEVERN	B
SEVILLE	D
SEVY	C
SEWARD	B
SEWELL	B
SEXTON	D
SEYMOUR	C
SHAAK	D
SHADELAND	C
SHAFFER	A
SHAKOPEE	C
SHALCAR	D
SHAM	D
SHAMBO	B
SHAMEL	B
SHANAHAN	B
SHANDON	
SHANE	D
SHANO	B
SHANTA	B
SHAPLEIGH	C/D
SHARATIN	B
SHARKEY	D
SHARON	B
SHARPSBURG	B
SHARVANA	C
SHASKIT	B/C
SHASTA	A
SHAVANO	B
SHAVER	B
SHAWANO	A
SHAWMUT	B
SHAY	D
SHEAR	C
SHECKLER	C
SHEDD	C
SHEEGE	D
SHEEP CREEK	C
SHEEPHEAD	C
SHEEPROCK	A
SHEETIRON	C
SHEFFIELD	D
SHELBURNE	C
SHELBY	B
SHELBYVILLE	B
SHELDON	
SHELIKOF	C
SHELLABARGER	B
SHELLDRAKE	A
SHELLROCK	A
SHELMADINE	D
SHELOCTA	B
SHELTON	C
SHENA	C
SHENANDOAH	C
SHEPPARD	A
SHERIDAN	B
SHERM	D
SHERRYL	B
SHIBLE	B
SHIELDS	C
SHIFFER	B
SHILOH	C
SHINAKU	C
SHINGLE	D
SHINGLETOWN	C
SHINN	B
SHINROCK	C
SHIOCTON	B
SHIPLEY	C
SHIPROCK	B
SHIRK	B
SHOALS	C
SHOEFFLER	B
SHONKIN	D
SHOOK	A
SHOREWOOD	C
SHOREY	B
SHORN	B
SHORT CREEK	D
SHOSHONE	D
SHOTWELL	D
SHOUNS	B
SHOWALTER	C
SHOWLOW	C
SHREWSBURY	D
SHRINE	B
SHROUTS	D
SHUBUTA	C
SHULE	B
SHULLSBURG	C
SHUMWAY	D
SHUPERT	C
SHUWAH	B
SI	B
SIBLEYVILLE	B
SIBYLEE	D
SICILY	B
SICKLESTEETS	C
SIDELL	B
SIEANCIA	B
SIEBER	A
SIELO	C
SIEROCLIFF	D
SIERRA	B
SIERRAVILLE	B
SIESTA	D
SIFTON	B
SIGNAL	D
SIGURD	B
SIKESTON	D
SILCOX	B
SILENT	D
SILER	B
SILERTON	B
SILI	D
SILVER	D
SILVERBOW	D
SILVER CREEK	D
SILVERTON	C
SILVIES	D
SIMAS	C
SIMCOE	C
SIMEON	A
SIMMLER	D
SIMNER	A
SIMON	C
SIMONA	B
SIMPERS	B
SIMPSON	C
SIMS	D
SINAI	C
SINCLAIR	B
SINE	C
SINGLETREE	D
SINGSAAS	B
SINNIGAM	C
SINUK	B
SION	B
SIOUX	A
SIPPLE	A
SISKIYOU	B
SISSETON	B
SISSON	B
SITES	C
SITKA	B
SIXMILE	B
SIZEMORE	B
SIZER	B
SKAGGS	B
SKAGIT	B/C
SKAHA	A
SKALAN	C
SKAMANIA	B
SKAMOKAWA	B
SKANEE	C
SKELLOCK	B
SKERRY	
SKILLET	C
SKINNER	C
SKIYOU	B
SKOKOMISH	B/C
SKOOKUMCHUCK	B
SKOWHEGAN	B
SKULL CREEK	D
SKUMPAH	D
SKUTUM	C
SKYBERG	C
SKYHAVEN	D
SKYKOMISH	B
SKYLINE	C
SKYWAY	B
SLAB	C
SLATE CREEK	C
SLAUGHTER	C
SLAVEN	C
SLAWSON	B
SLAYTON	C
SLEETH	C
SLETTEN	D
SLICKROCK	B
SLIGHTS	D
SLIGO	B
SLIKOK	C
SLIP	B
SLOAN	C
SLOCUM	B
SLODUC	C
SLOSS	C
SLUICE	B
SMARTS	B
SMITH CREEK	A
SMITHNECK	B
SMITHTON	D
SMOLAN	C
SMOOT	D
SNAG	B
SNAHOPISH	B
SNAKE	C
SNAKE HOLLOW	B
SNAKELUM	B
SNEAD	D
SNELL	C
SNELLING	B
SNOHOMISH	D
SNOQUALMIE	B
SNOW	B
SNOWDEN	C
SNOWLIN	B
SNOWVILLE	D
SNOWY	A
SOAP LAKE	B
SOBOBA	A
SOBRANTE	C
SODA LAKE	B
SODHOUSE	D
SODUS	C
SOELBERG	B
SOFIA	C
SOGN	D
SOGZIE	B
SOLANO	D
SOLDATNA	B
SOLDIER	D
SOL DUC	B
SOLLEKS	C
SOLLER	D
SOLOMON	D
SOLONA	B
SOMBRERO	D
SOMERS	B
SOMERSET	C
SOMERVELL	B
SOMSEN	C
SONOITA	B
SONOMA	D
SONTAG	C
SOPER	B
SOQUEL	B
SORF	C
SORRENTO	B
SORTER	B/D
SOSA	C
SOTELLA	C
SOUTHFORK	D
SOUTHGATE	C
SOUTHWICK	C
SPAA	D
SPACE CITY	A
SPADE	B
SPALDING	C
SPANAWAY	B
SPARTA	A
SPEARFISH	B
SPEARVILLE	C
SPECK	D
SPECTER	D
SPEELYAI	C
SPEIGLE	B
SPENARD	C
SPENCER	B
SPERRY	C
SPICER	C
SPILLVILLE	B
SPINKS	A
SPIRIT	B
SPIRO	B
SPLENDORA	C
SPLITROCK	D
SPOFFORD	C
SPOKANE	B
SPONSELLER	B
SPOON BUTTE	D
SPOONER	C
SPOTTSWOOD	B
SPRAGUE	B/C
SPRECKELS	C
SPRING	C/D
SPRING CREEK	C
SPRINGDALE	B
SPRINGER	B
SPRINGERVILLE	D
SPRINGFIELD	D
SPRINGMEYER	C
SPRINGTOWN	C
SPUR	B
SPURLOCK	B
SQUALICUM	B
SQUAW	B
SQUILLCHUCK	B
SQUIM	B
SQUIRES	B
STAATSBURG	
STABLER	B
STACY	B
STADY	B
STAFFORD	C
STAGECOACH	B
STAHL	C
STALEY	C
STAMBAUGH	B
STAMFORD	D
STAMPEDE	D
STAN	B
STANDISH	C/D
STANEY	D
STANFIELD	C
STANLEY	C
STANSBURY	D
STANTON	D
STAPLETON	B
STARBUCK	D
STARICHKOF	D
STARKS	C
STARR	B
STASER	B
STATE	B
STATEN	D
STAVE	C
STAYTON	D
STEAMBOAT	D
STEARNS	D
STECUM	A
STEED	A
STEEDMAN	D
STEEKEE	C
STEELE	B
STEESE	C
STEFF	C
STEGALL	C
STEIGER	A
STEINAUER	B
STEINBECK	B
STEINMETZ	D
STEINSBURG	C
STEINER	C
STELLAR	D
STEMILT	C
STENDAL	C
STEPHEN	C
STEPHENSBURG	B
STEPHENVILLE	B
STERLING	A
STERLINGTON	B

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EXHIBIT 2-1 January, 1971

STETSON	B	SUNSET	B	TALLAPOOSA	C	TENSAS	D	TIMKEN	D
STETTER	D	SUNSHINE	C	TALLEYVILLE	B	TENSED	C	TIMMERMAN	B
STEUBEN	B	SUNSWEET	C	TALLS	B	TENSLEEP	B	TIMPONS	B
STEVENS	B	SUPAN	B	TALLULA	B	TEOCULLI	B	TIMPAHUTE	D
STEVENSON	B	SUPERIOR	C	TALLY	B	TEPEE	D	TIMPANOGOS	B
STEWART	D	SUPERSTITION	A	TALMAGE	A	TEPETE	B/D	TIMPER	D
STICKNEY	C	SUPERVISOR	C	TALMO	B	TERINO	C	TIMPOONEKE	B
STIDHAM	A	SUPPLEE	B	TALOKA	D	TERMINAL	D	TIMULA	B
STIGLER	C	SUR	B	TALPA	D	TERMO	C	TINA	C
STILLMAN	A	SURGH	B	TAMA	B	TEROUGE	D	TINCAHAY	A
STILLWATER	D	SURPRISE	B	TAMALCO	D	TERRA CEIA	A/D	TINE	A
STILSON	B	SURRENCY	B/D	TAMBA	C/D	TERRAD	D	TINSLEY	A
STIMSON	B/C	SURVYA	C	TAMMANY CREEK	B	TERRERA	C	TINTON	A
STINGAL	B	SUSIE CREEK	D	TAMMS	C	TERRIL	B	TINYTOWN	B
STINSON	C	SUSITNA	B	TAMPICO	B	TERRY	B	TIOCANO	D
STIRK	D	SUSQUEHANNA	D	TANAMA	D	TERWILLIGER	C	TIOGA	B
STIRUM	B	SUTHER	C	TANANA	C	TESAJO	A	TIPPAH	C
STISSING		SUTHERLIN	C	TANBERG	D	TESCOTT	C	TIPPECANOE	B
STIVERSVILLE	B	SUTPHEN	D	TANDY	C	TESUQUE	B	TIPPER	A
STOCKBRIDGE	B	SUTTLER	B	TANEUM	C	TETON	A	TIPPERARY	A
STOCKLAND	B	SUTTON	B	TANEY	C	TETONIA	B	TIPPIPAH	D
STOCKPEN	D	SVEA	B	TANGAIR	C	TETONKA	C	TIPPO	C
STOCKTON	D	SVERDRUP	B	TANNA	C	TETOTUM	C	TIPTON	B
STODICK	D	SVOLD	C	TANNER	C	TEW	B/D	TIPTONVILLE	B
STOKES	D	SWAGER	C	TANSEM	B	TEX	B	TIRA	B
STOMAR	C	SWAKANE	B	TANTALUS	A	TEXLINE	B	TISBURY	B
STONER	B	SWAN	C	TANWAX	D	TEZUMA	C	TISCH	C
STONEWALL	A	SWANBOY	D	TAOPI	C	THACKERY	B	TISH TANG	B
STONO	B/D	SWANNER	D	TAOS	C	THADER	C	TITUSVILLE	C
STONYFORD	D	SWANSON	C	TAPIA	C	THANYON	A	TIVERTON	A
STOOKEY	B	SWANTON	B/D	TAPPEN	D	THATCHER	B	TIVOLI	A
STORDEN	B	SWANTOWN	C	TARA	B	THATUNA	C	TIVY	C
STORLA	B	SWAPPS	C	TARKIO	D	THAYNE	B	TOA	C
STORM KING	D	SWARTSWOOD	C	TARKLIN	C	THEBES	B	TOBICO	D
STORY	C	SWARTZ	D	TARPO	C	THEBO	D	TOBIN	B
STOSSEL	C	SWASEY	D	TARRANT	C	THEDULUND	C	TOBLER	B
STOUGH	C	SWASTIKA	C	TARYALL	B	THENAS	C	TOBOSA	D
STOWELL	D	SWATARA	A	TASCOSA	B	THERESA	B	TOBY	B
STOY	D	SWAUK	C	TASSEL	D	THERIOT	D	TOCCOA	B
STRAIGHT	C	SWAWILLA	A	TATE	B	THERMAL	C	TODD	B
STRAIN	B	SWEATMAN	C	TATIYEE	C	THERMOPOLIS	D	TODDLER	B
STRASBURG	C	SWEDE	B	TATU	C	THETFORD	A	TODDVILLE	B
STRATFORD	B	SWEDEN	B	TATUM	C	THIOKOL	C	TOEHEAD	C
STRAUSS	C	SWEEK	C	TAUNTON	C	THOENY	D	TOEJA	C
STRAW	B	SWEENEY	B	TAVARES	A	THOMAS	C	TOEM	C
STRAWN	B	SWEET	C	TAWAS	A/D	THORNDALE	D	TOGO	B
STREATOR	C	SWEETGRASS	B	TAYLOR	C	THORNDIKE	C/D	TOHONA	C
STROLE	B	SWEETWATER	D	TAYLOR CREEK	D	THORNOCK	D	TOINE	C
STRONGHURST	B	SWENODA	B	TAYLORSFLAT	D	THORNTON	C	TOIYABE	C
STRONTIA	B	SWIFTON	A	TAYLORSVILLE	C	THORNWOOD	B	TOKEEN	C
STROUPE	D	SWIMS	A	TAYSOM	B	THOROUGHFARE	B	TOKUL	B
STRYKER	B	SWINGLE	D	TAZLINA	A	THORP	C	TOLBY	B
STUKEL	C	SWISBOB	D	TEAL	D	THORR	B	TOLEDO	D
STUKY	B	SWITCHBACK	C	TEALWHIT	C	THORREL	B	TOLICHA	D
STUMBLE	A	SWITZERLAND	B	TEANAWAY	C	THOW	B	TOLL	A
STUMPP	D	SWOPE	C	TEAPO	B	THREE MILE	D	TOLLGATE	B
STUMP SPRINGS	B	SWYGERT	C	TEAS	C	THUNDERBIRD	D	TOLLHOUSE	D
STUTTGART	D	SYCAMORE	B	TEASDALE	B	THURBER	C	TOLNA	B
STUTZVILLE	B/C	SYCAN	A	TEBO	B	THURLONI	D	TOLO	B
SUBLETTE	B	SYLACAUGA	B/C	TECHICK	B	THURLOW	C	TOLSONA	D
SUDBURY	B	SYLVAN	B	TECOLOTE	B	THURMAN	A	TOLSTOI	D
SUFFIELD	C	SYMERTON	B	TECUMSAH	B	THURMONT	B	TOLT	D
SUGARLOAF	B	SYNAREP	B	TEDROW	B	THURSTON	B	TOLTEC	C
SUISUN	D	SYRACUSE	B	TEEL	B	TIAK	C	TOLUCA	B
SULA	B	SYRENE	D	TEHACHAPI	D	TIBBITTS	B	TOLVAR	B
SULLY	B	SYRETT	C	TEHAMA	C	TICA	D	TOMAH	C
SULPHURA	D			TEJA	D	TICE	C	TOMAS	B
SULTAN	B	TABERNASH	B	TEJON	B	TICHIGAN	C	TOMAST	C
SUMAS	B/C	TABIONA	B	TEKOA	C	TICHNOR	D	TOMERA	D
SUMDUM	D	TABLE MOUNTAIN	B	TELA	B	TICKAPOO	C	TOMICHI	A
SUMMA	B	TABLER	D	TELEFONO	D	TICKASON	B	TOMOKA	A/D
SUMMERFIELD	C	TABOR	C	TELEPHONE	D	TIDWELL	D	TONATA	C
SUMMERS	B	TACOMA	D	TELFER	A	TIERRA	D	TONAWANDA	C
SUMMERVILLE	C	TACOOSH	D	TELL	B	TIETON	B	TONEY	D
SUMMIT	C	TAFT	C	TELLER	B	TIFFANY	C	TONGUE RIVER	B
SUMMITVILLE	B	TAGGERT	C	TELLICO	B	TIFTON	B	TONINI	B
SUMTER	C	TAHOMA	B	TELLMAN	B	TIGER CREEK	B	TONKA	C
SUN	D	TAHQUAMENON	D	TELSTAD	B	TIGERON	A	TONKEY	C
SUNBURST	C	TAHQUATS	C	TEMESCAL	D	TIGIWON	B	TONKS	B
SUNBURY	B	TAINTOR	C	TEMPLE	B/C	TIGNETT		TONOPAH	B
SUNCOOK	A	TAJO	C	TEMVIK	B	TIGUA	D	TONOWEK	B
SUND	C	TAKEUCHI	C	TENABO	D	TIJERAS	B	TONSINA	B
SUNDELL	C	TAKILMA	B	TENAHA	B	TILFORD	B	TONUCO	B
SUNDERLAND	C/D	TAKOTNA	B	TENAS	C	TILLEDA	B	TOOLE	D
SUNDOWN	B	TALANTE	C	TENCEE	C	TILLICUM	B	TOOMES	D
SUNFIELD	B	TALAPUS	B	TENERIFFE	C	TILLMAN	C	TOP	C
SUNNILAND	C	TALBOTT	C	TENEX	A	TILMA	C	TOPPENISH	B/C
SUNNYHAY	D	TALCOT	C	TENIBAC	B	TILSIT	C	TOPTON	
SUNNYSIDE	B	TALIHINA	D	TENINO	B	TILTON	B	TOQUERVILLE	D
SUNNYVALE	C	TALKEETNA	C	TENNO	D	TIMBERG	C	TOQUOP	A
SUNRAY	C	TALLAC	B	TENOT	C	TIMBERLY	B	TORBOY	B
SUNRISE	C	TALLAPECA	C	TEN[illegible]	B	TIMENTWA	B	TORCHLIGHT	C

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January, 1971

EXHIBIT 2-1

TORHUNTA	C	TRUCKEE	C	UKIAH	C	VASHTI	C	VOLINIA	B
TORNING	B	TRUCKTON	B	ULEN	B	VASQUEZ	B	VOLKE	C
TORODA	B	TRUESDALE	C	ULLOA	B	VASSAR	B	VOLKMAR	B
TORONTO	C	TRULL	C	ULM	B	VASTINE	C	VOLNEY	B
TORPEDC LAKE	C	TRULON	B	ULRICHER	B	VAUCLUSE	C	VOLPERIE	C
TORREON	C	TRUMAN	B	ULUPALAKUA	B	VAUGHNSVILLE	C	VOLTAIRE	D
TORRES	B	TRUMBULL	D	ULYSSES	B	VAYAS	D	VOLUSIA	C
TORRINGTON	B	TRUMP	D	UMA	A	VEAL	B	VONA	B
TORRO	C	TRYON	D	UMAPINE	B/C	VEAZIE	B	VORE	B
TORTUGAS	D	TSCHICOMA	C	UMIKCA	B	VEBAR	B	VRCCMAN	B
TOTEM	B	TUB	C	UMIL	D	VEBAR	B	VULCAN	C
TOTTEN	B	TUBAC	C	UMNAK	B	VEGA	C	VYLACH	D
TOUCHET	B	TUCANNON	C	UMPA	B	VEGA ALTA	C		
TOUHEY	B	TUCKERMAN	D	UNA	D	VEGA BAJA	C	WABANICA	D
TOULON	B	TUCUMCARI	C	UNACILLA	B	VEKOL	D	WABASH	D
TOURN	C	TUFFIT	D	UNAWEEP	B	VELMA	B	WABASHA	D
TOURNQUIST	B	TUGHILL	D	UNCCMPAGHRE	C	VELVA	B	WABASSA	B/D
TOURS	B	TUJUNGA	A	UNEEDA	B	VENA	B	WABEK	B
TOUTLE	A	TUKEY	C	UNGERS	B	VENANGO	C	WACA	C
TOWER	D	TUKWILA	D	UNICN	C	VENATOR	D	WACCTA	B
TOWNER	B	TULA	C	UNIONTOWN	B	VENETA	C	WACCUSTA	C
TOWNLEY	C	TULANA	C/D	UNICNVILLE	C	VENEZIA	D	WADAMS	B
TOWNSBURY	B	TULARE	C/D	UNISCN	C	VENICE	D	WADCELL	B
TOWNSEND	C	TULAROSA	C	UPSAL	C	VENLC	D	WADDOUPS	B
TOWSON	B	TULIA	B	UPSHUR	C	VENUS	B	WADENA	B
TOXAWAY	D	TULLER	D	UPTCN	C	VERBCORT	D	WADESBORO	B
TOY	D	TULLOCK	B	URACCA	B	VERDE	C	WADLEIGH	C
TOYAH	B	TULLY	C	URBANA	C	VERDEL	D	WADMALAW	D
TOZE	B	TUMBEZ	D	URBG	D	VERDELLA	D	WADSWORTH	C
TRABUCO	C	TUMEY	D	URICH	D	VERDIGRIS	B	WAGES	B
TRACK	B	TUMITAS	B	URNE	B	VERDUN	D	WAGNER	D
TRACY	B	TUMWATER	A	URSINE	D	VERGENNES	D	WAGRAM	A
TRAER	C	TUNEHEAN	D	URTAH	C	VERHALEN	C	WAHA	C
TRAIL	A	TUNICA	D	URWIL	D	VERMEJC	D	WAHEE	D
TRAIL CREEK	B	TUNIS	D	USAL	B	VERNAL	B	WAHIAWA	B
TRANSYLVANIA	B	TUNKHANNOCK	A	USPAR	B	VERNALIS	B	WAHIKULI	B
TRAPPER	A	TUNNEL	B	USINE	B	VERNON	D	WAHKEENA	B
TRAPPIST	C	TUPELO	D	USKA	D	VERONA	C	WAHKIACUS	B
TRASK	C	TUPUKNUK	D	UTALINE	B	VESSER	C	WAHLUKE	B
TRAVER	B/C	TURBEVILLE	C	UTE	C	VESTON	D	WAHPETON	C
TRAVESSILLA	D	TURBOTVILLE	C	UTICA	A	VETAL	A	WAHTIGUP	B
TRAVIS	C	TURBYFILL	B	UTLEY	B	VETERAN	B	WAHTUM	B/C
TRAWICK	B	TURIN	B	UTUACO	B	VEYC	D	WAIAHA	D
TRAY	C	TURK	D	UVADA	D	VIA	B	WAIAKOA	C
TREADWAY	D	TURKEYSPRINGS	C	UVALDE	C	VIAN	B	WAIALEALE	D
TREASURE	B	TURLEY	C	UWALA	B	VIBORAS	D	WAIALUA	B
TREBLOC	D	TURLIN	B			VIBORG	B	WAIAWA	D
TREGO	C	TURNBOW	C	VACHERIE	C	VICKERY	C	WAIHUNA	D
TRELONA	D	TURNER	B	VADER	B	VICKSBURG	B	WAIKALCA	B
TREMBLES	B	TURNERVILLE	B	VADC	A	VICTCR	A	WAIKANE	B
TREMPE	A	TURNEY	B	VAIDEN	D	VICTCRIA	D	WAIKAPU	B
TREMPEALEAU	B	TURRET	B	VAILTCN	B	VICTCRY	B	WAIKOMO	D
TRENARY	B	TURRIA	C	VALCC	C	VICU	D	WAILUKU	B
TRENT	B	TUSCAN	D	VALCEZ	B/C	VIUA	B	WAIPEA	B
TRENTON	D	TUSCARAWAS	C	VALE	B	VIDRINE	C	WAINEE	B
TREP	B	TUSCARORA	C	VALENCIA	B	VIENNA	B	WAINOLA	A
TRES HERMANOS	C	TUSCOLA	B	VALENT	A	VIEQUES	B	WAIPAHU	C
TRES HERMANOS	C	TUSCUMBIA	C	VALENTINE	A	VIEW	C	WAISKA	B
TRETTEN	C	TUSEL	C	VALFPA	C	VIGAR	C	WAITS	B
TREVINO	D	TUSKEEGO	C	VALKARIA	B/D	VIGO	D	WAKE	D
TREXLER	C	TUSLER	B	VALLAN	D	VIKING	D	WAKEEN	B
TRIAMI	C	TUSQUITEE	B	VALLECITCS	C	VIL	D	WAKEFIELD	B
TRIASSIC		TUSTIN	B	VALLFRS	C	VILAS	A	WAKELAND	B/D
TRICON	C	TUSTUMENA	B	VALPONT	C	VILLA GRCVE	B	WAKCNDA	C
TRIDELL	B	TUTHILL	B	VALPY	B	VILLARS	B	WALCOTT	B
TRIDENT	D	TUTTLE	B	VALCIS	B	VINA	B	WALCECK	C
TRIGO	C	TUTWILER	B	VANAJC	D	VINCENNES	C	WALDO	D
TRIMBLE	B	TUXEDO		VANANDA	D	VINCENT	C	WALCRGN	D
TRIMMER	B	TUXEKAN	B	VAN BUREN		VINEYARD	C	WALDROUP	D
TRINCHERA	C	TWILACKS	A	VANCE	C	VINGC	B	WALES	C
TRINITY	D	TWIN CREEK	B	VANDA	D	VINING	C	WALFCRD	C
TRIPLEN	C	TWINING	C	VANDALIA	C	VINITA	C	WALKE	C
TRIPOLI	C	TWISP	B	VANCERDASSCN	D	VINLAND	C	WALL	B
TRIPP	B	TWO DOT	C	VANDERGRIFT	C	VINTON	B	WALLACE	B
TRITON	C	TYEE	D	VANDERHCFF	D	VIRA	C	WALLA WALLA	B
TRIX	B	TYGART	D	VANDERLIP	A	VIRATCN	C	WALLER	B/D
TROJAN	B	TYLER	D	VAN DUSEN	B	VIRDEN	C	WALLINGTON	C
TROMMALD	D	TYNDALL	B/C	VANET	C	VIRGIL	B	WALLIS	B
TROMP	B/C	TYNER	A	VANG	B	VIRGIN PEAK	D	WALLKILL	C/D
TRONSEN	B	TYRONE	C	VANHORN	B	VIRGIN RIVER	D	WALLMAN	C
TROOK	B	TYSON	C	VAN NCSTERN	B	VIRTUE	B	WALLOWA	C
TROPAL	D			VANNCY	B	VISALIA	B	WALLPACK	
TROSI	D	UBAR	C	VANUSS	B	VISTA	C	WALLROCK	B
TROUP	A	UBLY	B	VANTAGE	C	VIVES	B	WALLSBURG	D
TROUT CREEK	C	UCOLA	C	VAN WAGONER	D	VIVI	B	WALLSON	B
TROUTDALE	B	UCCPIA	B	VARCO	C	VLASATY	C	WALPOLE	C
TROUT LAKE	C	UOEL	D	VARELUM	C	VCCA	C	WALSH	B
TROUT RIVER	A	UDOLPHO	C	VARICK	D	VODERMAIER	B	WALSHVILLE	D
TROUTVILLE	B	UFFENS	D	VARINA	C	VCLADORA	B	WALTERS	A
TROXEL	B	UGAK	D	VARNA	C	VCLENTE	C	WALTON	C
TROY	C	UHLIG	B	VARRC	B	VOLGA	D	WALLM	B
TRUCE	C	UINTA	B	VARYSBURG	B	VOLIN	B	WALVAN	B

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WAMBA	B/C
WAMIC	B
WAMPSVILLE	B
WANATAH	B
WANBLEE	D
WANDO	A
WANETTA	A
WANN	A
WANK	A
WAPAL	B
WAPATO	C/D
WAPELLO	B
WAPINITIA	B
WAPPING	B
WAPSIE	B
WARBA	B
WARD	D
WARDBORO	A
WARDELL	C
WARDEN	B
WARDWELL	C
WARE	B
WAREHAM	C
WARMAN	D
WARM SPRINGS	C
WARNERS	A/D
WARREN	
WARRENTON	B/D
WARRIOR	
WARSAW	B
WARSING	B
WARWICK	A
WASATCH	A
WASEPI	B
WASHBURN	
WASHINGTON	B
WASHOE	C
WASHOUGAL	B
WASHTENAW	C/D
WASILLA	C
WASIOJA	C
WASSAIC	B
WATAB	C
WATAUGA	B
WATCHAUG	B
WATCHUNG	D
WATERBORO	
WATERBURY	D
WATERINO	C
WATERS	C
WATKINS	B
WATKINS RIDGE	B
WATOPA	B
WATROUS	B
WATSEKA	C
WATSON	C
WATSONIA	D
WATSONVILLE	D
WATT	D
WATTON	C
WAUBAY	B
WAUBEEK	B
WAUBONSIE	B
WAUCHULA	B/D
WAUCOMA	B
WAUCONDA	B
WAUKEE	B
WAUKEGAN	B
WAUKENA	D
WAUKON	B
WAUMBEK	B
WAUPIKA	D
WAUSEON	B/D
WAVERLY	B/D
WAWAKA	C
WAYCUP	B
WAYDEN	D
WAYLAND	C/D
WAYNE	B
WAYNESBORO	B
WAYSIDE	
WEA	B
WEAVER	C
WEBB	C
WEBER	B
WEBSTER	C
WEDGE	A
WEDOWEE	B
WEED	C
WEEDING	A
WEEDMARK	B
WELKSVILLE	B/D
WEHADKEE	D
WEIKERT	C/D
WEIMER	D
WEINBACH	C
WEIR	D
WEIRMAN	B
WEISER	C
WEISHAUPT	C
WEISS	A
WEITCHPEC	B
WELBY	B
WELCH	C
WELD	C
WELDA	C
WELDON	C
WELDONA	B
WELLER	C
WELLERHORN	C
WELLINGTON	D
WELLMAN	B
WELLNER	B
WELLSBORO	C
WELLSTON	B
WELLSVILLE	B
WEMPLE	B
WENAS	B/C
WENATCHEE	C
WENDEL	B/C
WENHAM	
WENONA	C
WENTWORTH	B
WEPNER	B
WESO	C
WESSEL	B
WESTBROOK	D
WESTBURY	C
WESTCREEK	B
WESTERVILLE	C
WESTFALL	C
WESTFIELD	
WESTFORD	
WESTLAND	B/D
WESTMINSTER	C/D
WESTMORE	B
WESTMORELAND	B
WESTON	D
WESTPHALIA	B
WESTPLAIN	C
WESTPORT	A
WESTVILLE	B
WETHERSFIELD	C
WETHEY	B/C
WETZEL	D
WEYMOUTH	B
WHALAN	B
WHARTON	C
WHATCOM	C
WHATELY	D
WHEATLEY	D
WHEATRIDGE	C
WHEATVILLE	B
WHEELER	B
WHEELING	B
WHEELOCK	C
WHEELON	D
WHELCHEL	B
WHETSTONE	B
WHIDBEY	B
WHIPPANY	C
WHIPSTOCK	C
WHIRLO	C
WHIT	B
WHITAKER	C
WHITCOMB	C
WHITE BIRD	C
WHITECAP	D
WHITEFISH	B
WHITEFORD	B
WHITEHORSE	B
WHITE HOUSE	C
WHITELAKE	B
WHITELAW	B
WHITEMAN	D
WHITEROCK	D
WHITESBURG	C
WHITE STORE	D
WHITE SWAN	C
WHITEWATER	B
WHITEWOOD	C
WHITLEY	B
WHITLOCK	B
WHITMAN	D
WHITNEY	B
WHITORE	A
WHITSOL	B
WHITSON	D
WHITWELL	C
WHOLAN	C
WIBAUX	D
WICHITA	C
WICHUP	D
WICKERSHAM	B
WICKETT	C
WICKHAM	B
WICKIUP	C
WICKLIFFE	
WICKSBURG	B
WIDTSOE	C
WIEHL	C
WIEN	D
WIGGLETON	B
WILBRAHAM	C
WILBUR	C
WILCO	C
WILCOX	D
WILCOXSON	C
WILDCAT	D
WILDER	B
WILDERNESS	C
WILDROSE	D
WILDWOOD	D
WILEY	C
WILKES	C
WILKESON	C
WILKINS	D
WILL	D
WILLACY	B
WILLAKENZIE	C
WILLAMAR	D
WILLAMETTE	B
WILLAPA	C
WILLARD	C
WILLETTE	A/D
WILLHAND	B
WILLIAMS	B
WILLIAMSBURG	B
WILLIAMSON	C
WILLIS	C
WILLITS	B
WILLOUGHBY	B
WILLOW CREEK	B
WILLOWDALE	B
WILLOWS	D
WILLWOOD	A
WILMER	C
WILPAR	D
WILSON	D
WILTSHIRE	C
WINANS	B/C
WINCHESTER	A
WINCHUCK	C
WINDER	B/D
WINDMILL	B
WINDOM	B
WIND RIVER	B
WINDSOR	A
WINDTHORST	C
WINDY	C
WINEG	B
WINEMA	C
WINETTI	B
WINFIELD	C
WING	D
WINGATE	B
WINGER	C
WINGVILLE	B/D
WINIFRED	C
WINK	B
WINKLEMAN	C
WINLO	D
WINLOCK	C
WINN	C
WINNEBAGO	B
WINNEMUCCA	B
WINNESHIEK	B
WINNETT	D
WINONA	D
WINOOSKI	B
WINSTON	A
WINTERS	C
WINTERSBURG	B
WINTERSET	C
WINTHROP	A
WINTONER	C
WINU	C
WINZ	C
WIOTA	B
WISHEYLU	C
WISKAH	C
WISNER	D
WITBECK	D
WITCH	D
WITHAM	D
WITHEE	C
WITT	C
WITZEL	D
WODEN	B
WODSKOW	B
WOLCOTTSBURG	
WOLDALE	C/D
WOLF	B
WOLFESEN	C
WOLFORD	B
WOLF POINT	D
WOLFTEVER	C
WOLVERINE	A
WOODBINE	B
WOODBRIDGE	C
WOODBURN	C
WOODBURY	D
WOODCOCK	B
WOODENVILLE	C
WOODGLEN	D
WOODHURST	A
WOODLY	B
WOODLYN	C
WOODMANSIE	B
WOODMERE	B
WOOD RIVER	C
WOODROCK	B
WOODROW	C
WOODS CROSS	D
WOODSFIELD	C
WOODSIDE	A
WOODSON	D
WOODSTOCK	C/D
WOODSTOWN	C
WOODWARD	B
WOOLMAN	B
WOOLPER	C
WOOLSEY	C
WOOSLEY	B
WOOSTER	C
WOOSTERN	B
WOOTEN	A
WORCESTER	B
WORF	D
WORK	C
WORLAND	B
WORLEY	C
WORMSER	C
WOROCK	B
WORSHAM	D
WORTH	C
WORTHEN	B
WORTHING	D
WORTHINGTON	C
WORTMAN	C
WRENTHAM	C
WRIGHT	C
WRIGHTSVILLE	D
WUNJEY	B
WURTSBORO	C
WYALUSING	D
WYARD	B
WYARNO	C
WYATT	C
WYEAST	C
WYEVILLE	C
WYGANT	B
WYKOFF	B
WYMAN	B
WYMORE	C
WYNN	B
WYNOOSE	D
WYO	B
WYOCENA	B
YACOLT	B
YAHARA	B
YAHOLA	B
YAKIMA	B
YAKUS	D
YALLANI	B
YALMER	B
YAMHILL	C
YAMPA	C
YAMSAY	D
YANA	B
YAQUINA	B/D
YARDLEY	C
YATES	D
YAWDIM	D
YAWKEY	C
YAXON	B
YEATES HOLLOW	C
YEGEN	B
YELM	B
YENRAB	A
YEOMAN	B
YETULL	A
YODER	B
YOKOHL	C
YOLLABOLLY	D
YOLO	B
YOLOGO	D
YOMONT	B
YONCALLA	C
YONGES	D
YONNA	B/D
YORDY	B
YORK	C
YORKVILLE	D
YOST	C
YOUGA	B
YOUMAN	C
YOUNGSTON	B
YOURAME	A
YOVIMPA	D
YSIDORA	C
YTURBIDE	A
YUBA	D
YUKON	D
YUNES	D
YUNQUE	C
ZAAR	D
ZACA	C
ZACHARIAS	B
ZACHARY	D
ZAFRA	B
ZAHILL	B
ZAHL	B
ZALESKI	C
ZALLA	A
ZAMORA	B
ZANE	C
ZANEIS	B
ZANESVILLE	C
ZANONE	C
ZAPATA	C
ZAVALA	B
ZAVCO	C
ZEB	B
ZEESIX	C
ZELL	B
ZEN	C
ZENDA	C
ZENIA	B
ZENIFF	B
ZEONA	A
ZIEGLER	C
ZIGWEID	B
ZILLAH	B/C
ZIM	D
ZIMMERMAN	A
ZING	C
ZINZER	B
ZION	C
ZIPP	C/D
ZITA	B
ZOAR	C
ZOHNER	B/D
ZOOK	C
ZORRAVISTA	A
ZUFELT	B
ZUMBRO	B
ZUMWALT	C
ZUNDELL	B
ZUNHALL	B
ZUNI	C
ZURICH	B

NOTES A BLANK HYDROLOGIC SOIL GROUP INDICATES THE SOIL GROUP HAS NOT BEEN DETERMINED
TWO SOIL GROUPS SUCH AS B/C INDICATES THE DRAINED/UNDRAINED SITUATION

EXHIBIT 2-1

January, 1971

Description	Hydrologic Soil Group			
	A	B	C	D
Cultivated - without conservation treatment	72	81	88	91
- with conservation treatment	62	71	78	81
Pasture or range - poor condition	68	79	86	89
- good condition	39	61	74	80
Meadow	30	58	71	78
Woods or Forest - thin stand, poor cover, no mulch	45	66	77	83
- good cover	25	55	70	77
Farmsteads	59	74	82	86
Roads	74	84	90	92

Note: The underlined CN's are below the values in ES-1026 and ES-1027 charts. Use CN 60 for these conditions unless the job warrants computing the peak discharge by special procedures.(1)(2)

Exhibit 2-2 Runoff curve numbers (CN's)

CONTERMINOUS UNITED STATES

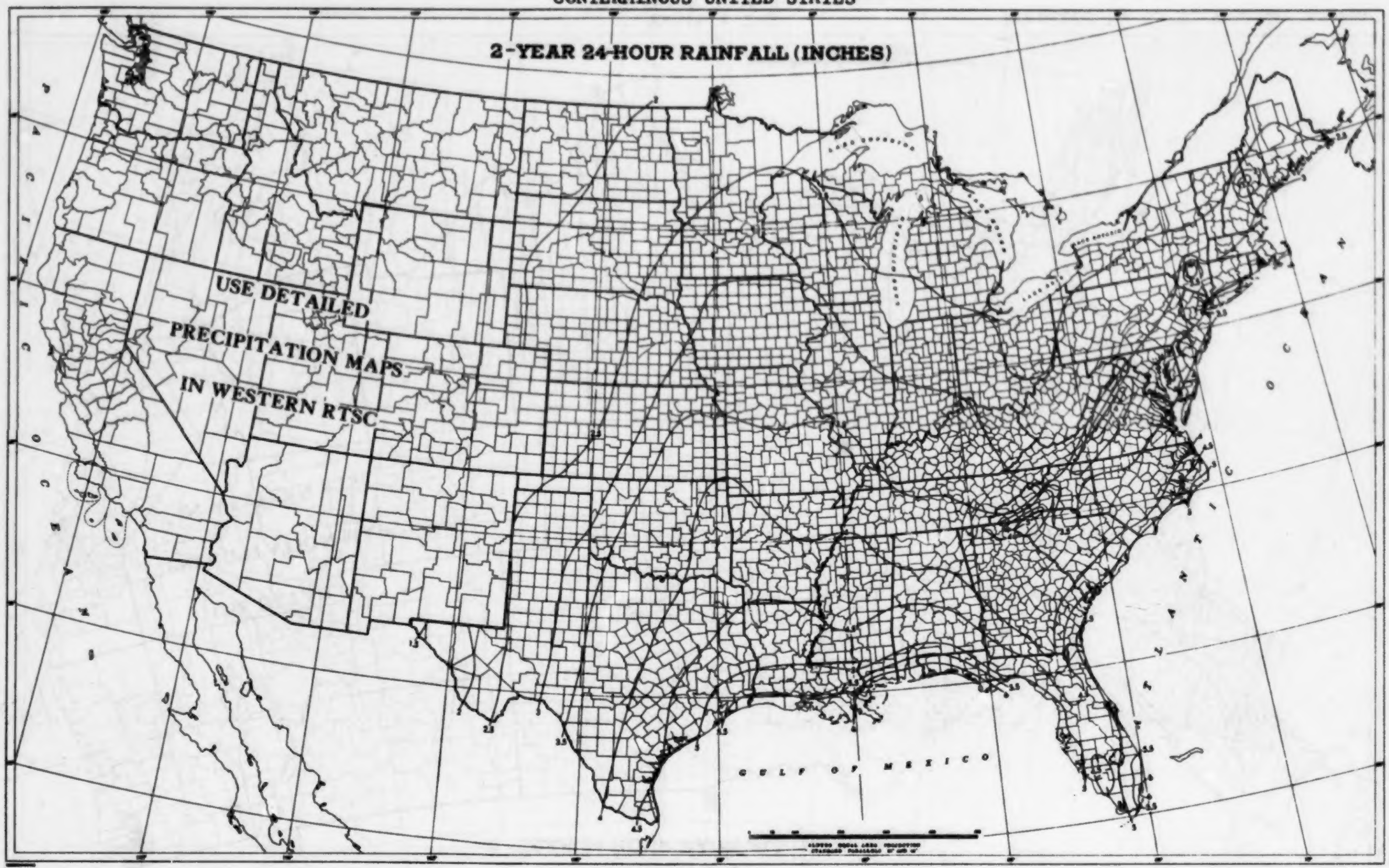

2-YEAR 24-HOUR RAINFALL (INCHES)
USE DETAILED PRECIPITATION MAPS IN WESTERN RTSC
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO

Exhibit 2-3
Sheet 1 of 5

Prepared by U. S. Weather Bureau

CONTERMINOUS UNITED STATES

5-YEAR 24-HOUR RAINFALL (INCHES)

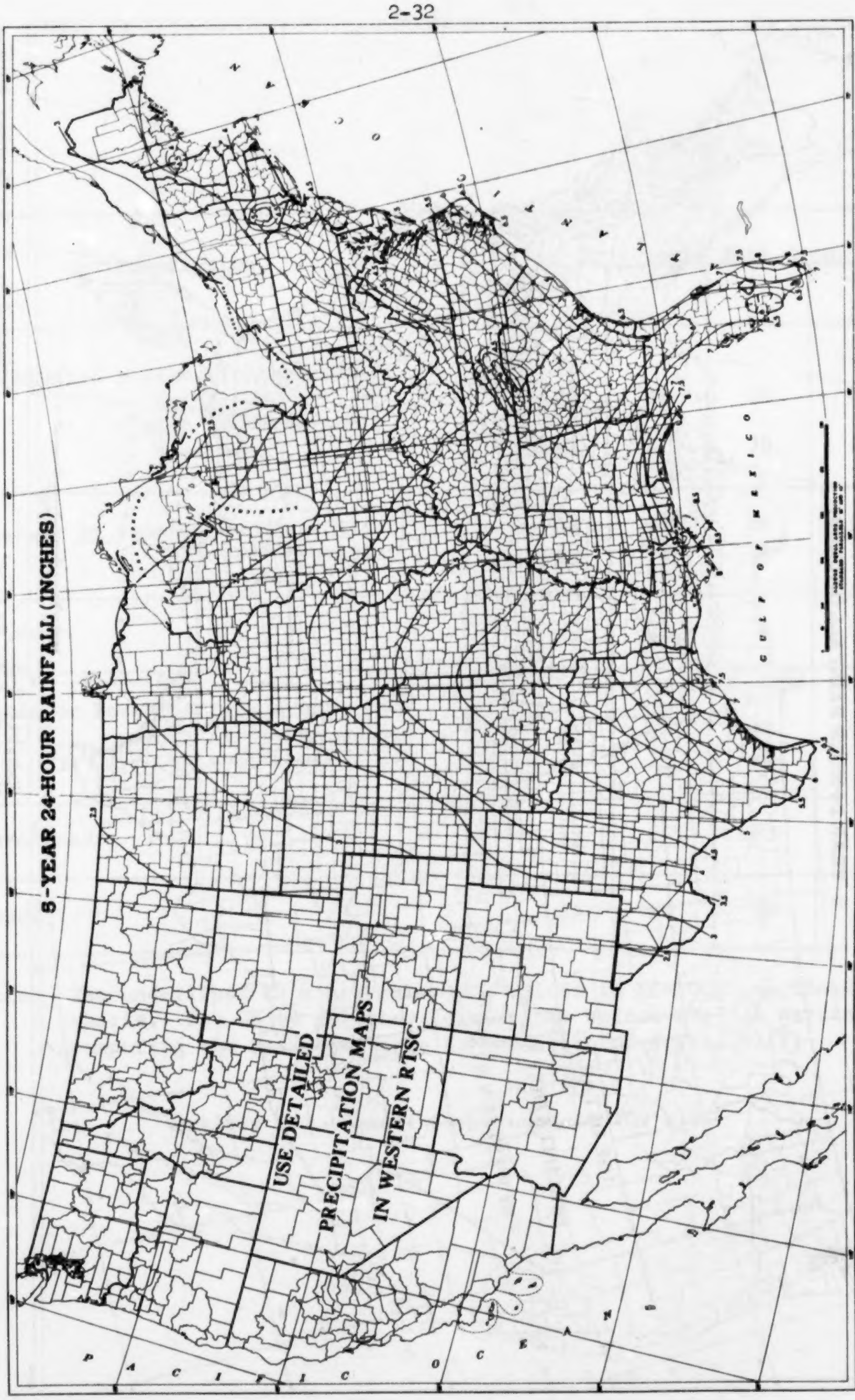

USE DETAILED
PRECIPITATION MAPS
IN WESTERN RTSC
PACIFIC OCEAN
GULF OF MEXICO

Exhibit 2-3
Sheet 2 of 5

Prepared by U. S. Weather Bureau

CONTERMINOUS UNITED STATES

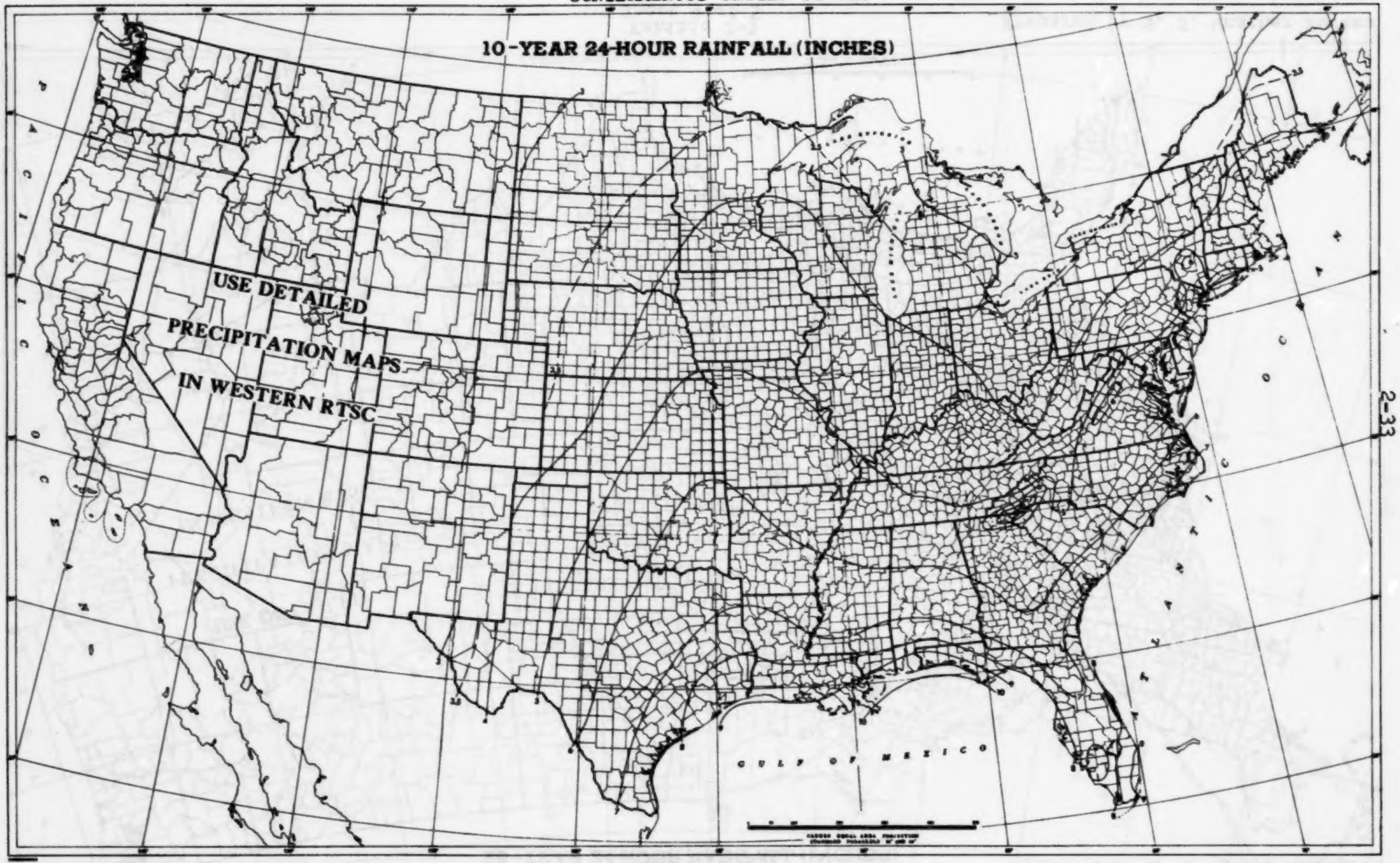
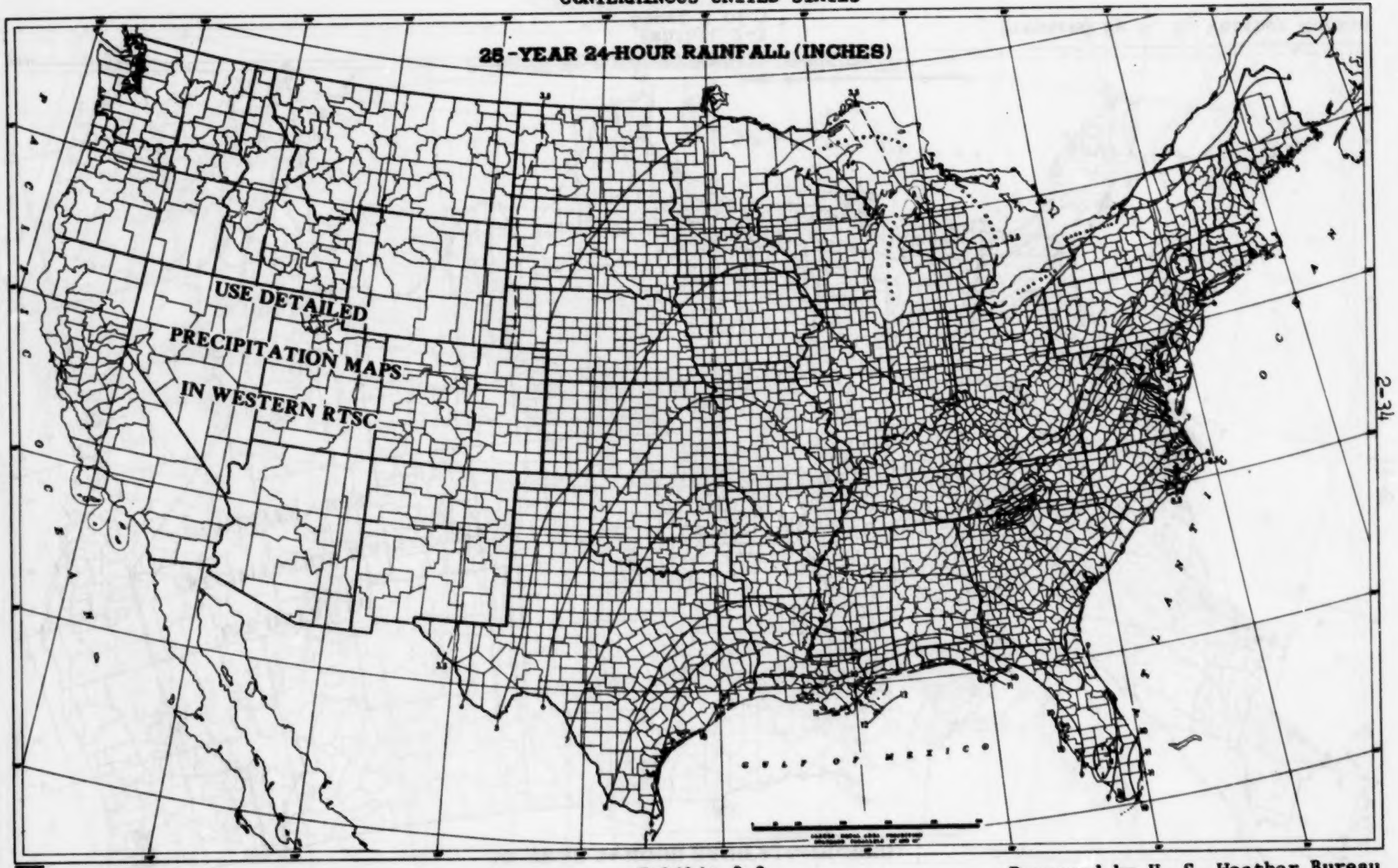

10-YEAR 24-HOUR RAINFALL (INCHES)
USE DETAILED
PRECIPITATION MAPS
IN WESTERN RTSC
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO

Exhibit 2-3
Sheet 3 of 5

Prepared by U. S. Weather Bureau



CONTERMINOUS UNITED STATES

25-YEAR 24-HOUR RAINFALL (INCHES)

USE DETAILED
PRECIPITATION MAPS
IN WESTERN RTSC
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO

Exhibit 2-3
Sheet 4 of 5

Prepared by U. S. Weather Bureau

CONTERMINOUS UNITED STATES

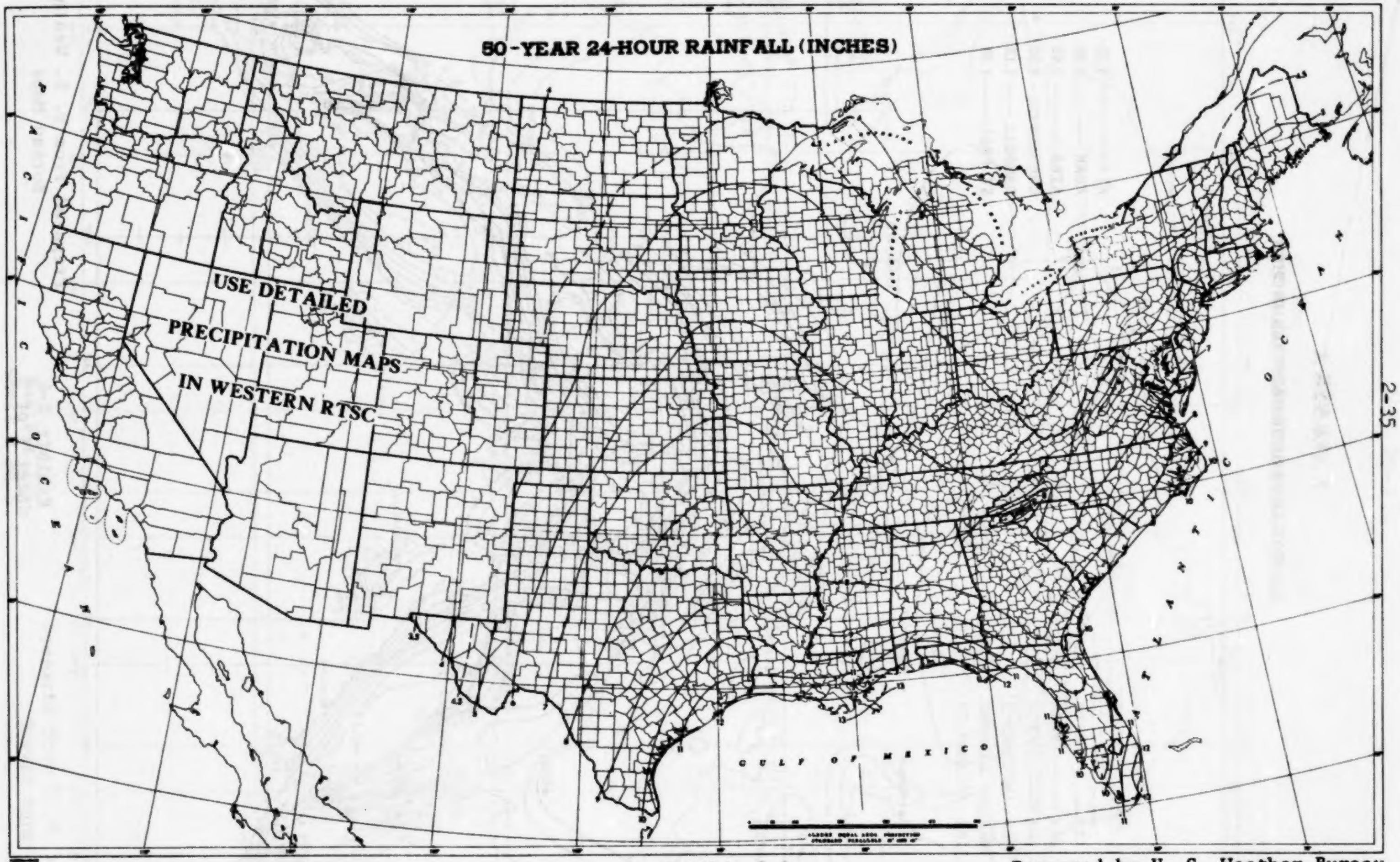

50-YEAR 24-HOUR RAINFALL (INCHES)
USE DETAILED
PRECIPITATION MAPS
IN WESTERN RTSC
PACIFIC OCEAN
GULF OF MEXICO
ATLANTIC OCEAN

Exhibit 2-3
Sheet 5 of 5

Prepared by U. S. Weather Bureau

ALASKA

2-YEAR 24-HOUR RAINFALL (INCHES)

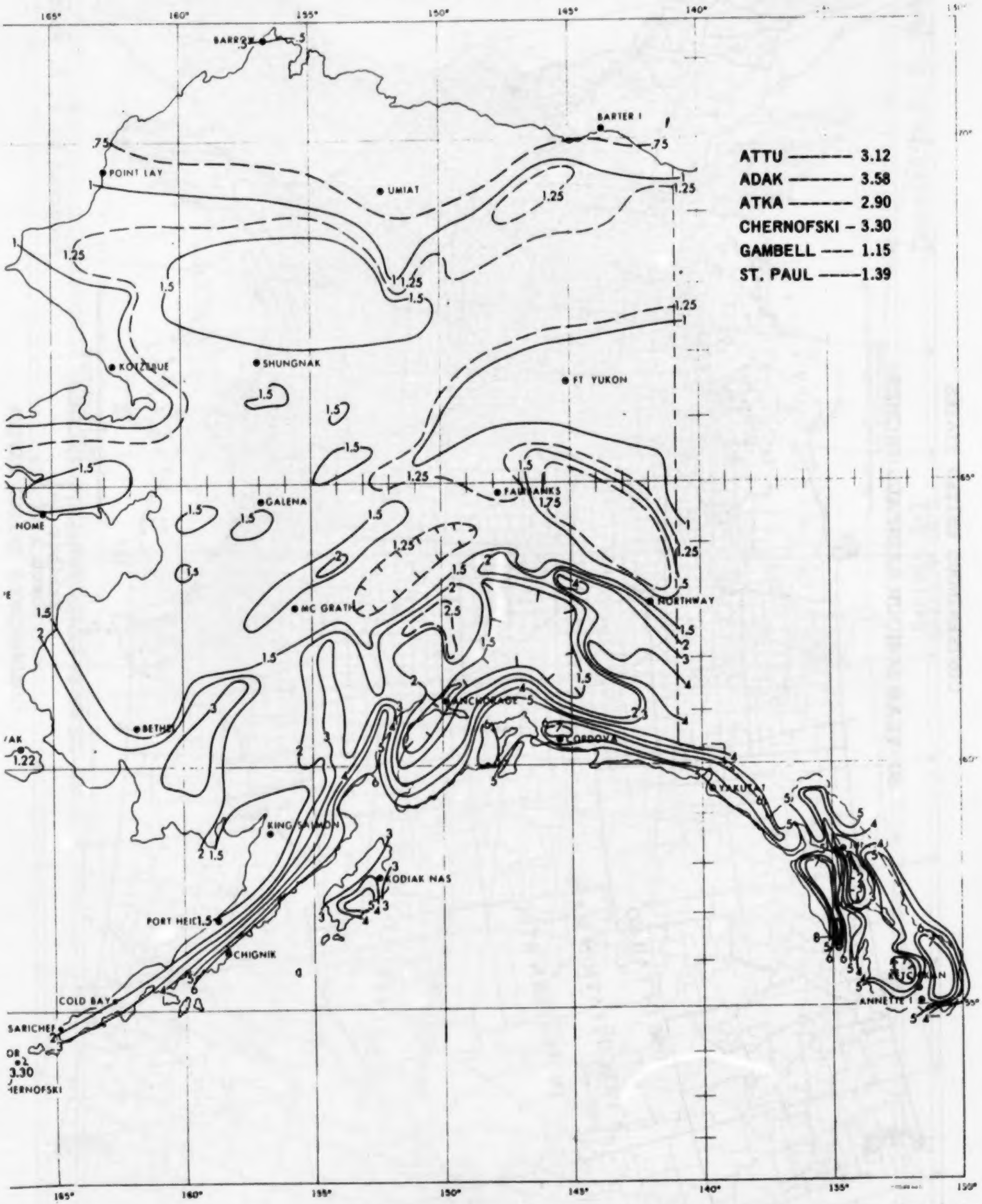
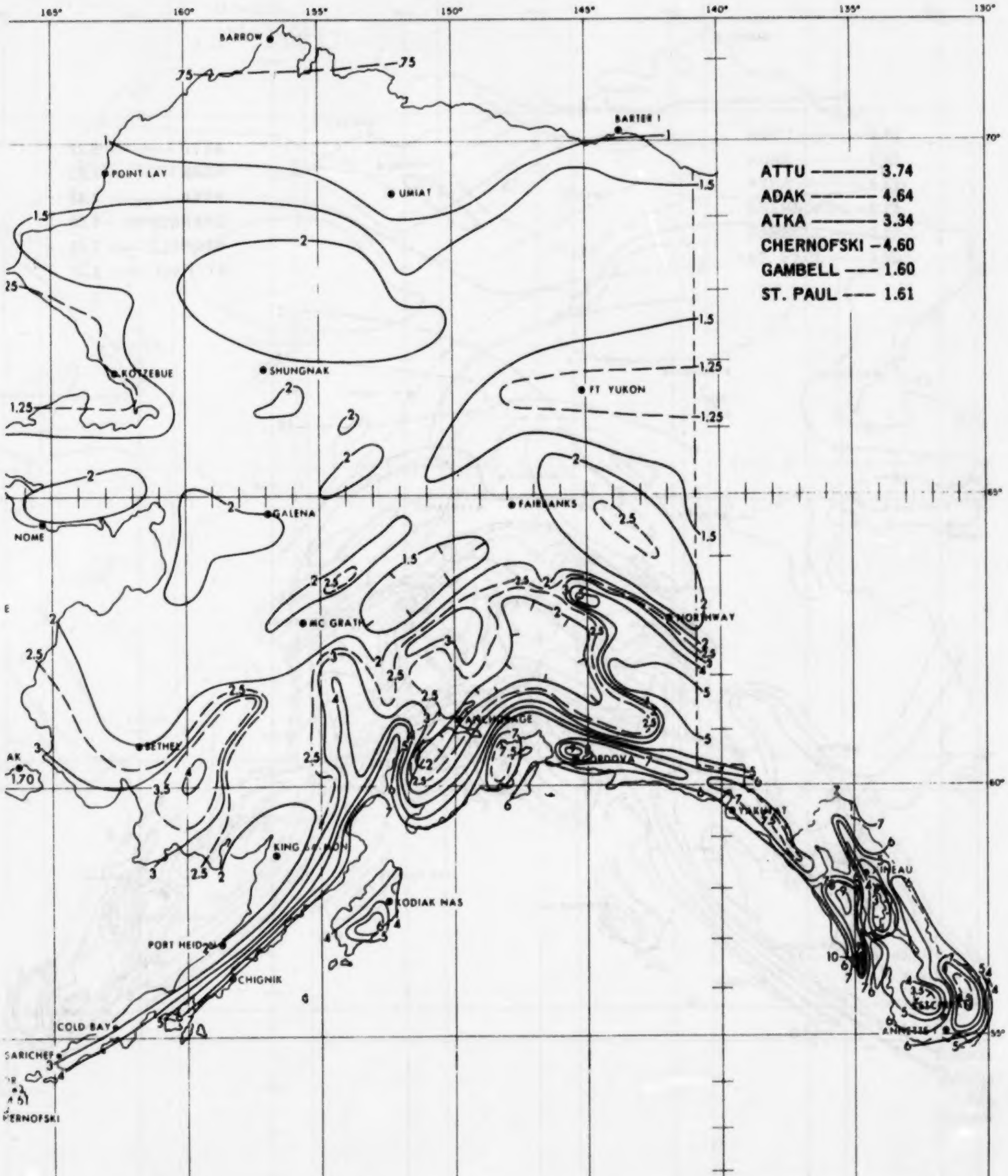

ATTU ------- 3.12
ADAK ------- 3.58
ATKA ------- 2.90
CHERNOFSKI - 3.30
GAMBELL ---- 1.15
ST. PAUL -----1.39
BARROW
POINT LAY
UMIAT
BARTER I
KOTZEBUE
SHUNGNAK
FT YUKON
NOME
GALENA
FAIRBANKS
MC GRATH
NORTHWAY
BETHEL
ANCHORAGE
CORDOVA
YAKUTAT
KING SALMON
KODIAK NAS
PORT HEIDEN
CHIGNIK
COLD BAY
SARICHEF
CHERNOFSKI
KETCHIKAN
ANNETTE I
165°
160°
155°
150°
145°
140°
135°
130°
70°
65°
60°
55°

Exhibit 2-4
Sheet 1 of 5

Prepared from U. S. Weather Bureau Maps

ALASKA

5-YEAR 24-HOUR RAINFALL (INCHES)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ADAK ------- 4.64
ATKA ------- 3.34
CHERNOFSKI - 4.60
GAMBELL --- 1.60
ST. PAUL --- 1.61
BARROW
BARTER I
POINT LAY
UMIAT
KOTZEBUE
SHUNGNAK
FT YUKON
NOME
GALENA
FAIRBANKS
MC GRATH
NORTHWAY
ANCHORAGE
CORDOVA
YAKUTAT
JUNEAU
BETHEL
KING SALMON
KODIAK NAS
PORT HEIDEN
CHIGNIK
COLD BAY
SARICHEF
CHERNOFSKI
KETCHIKAN
ANNETTE
1.70
165°
160°
155°
150°
145°
140°
135°
130°
70°
65°
60°
55°

Exhibit 2-4
Sheet 2 of 5

Prepared from U. S. Weather Bureau Maps

ALASKA

10-YEAR 24-HOUR RAINFALL (INCHES)

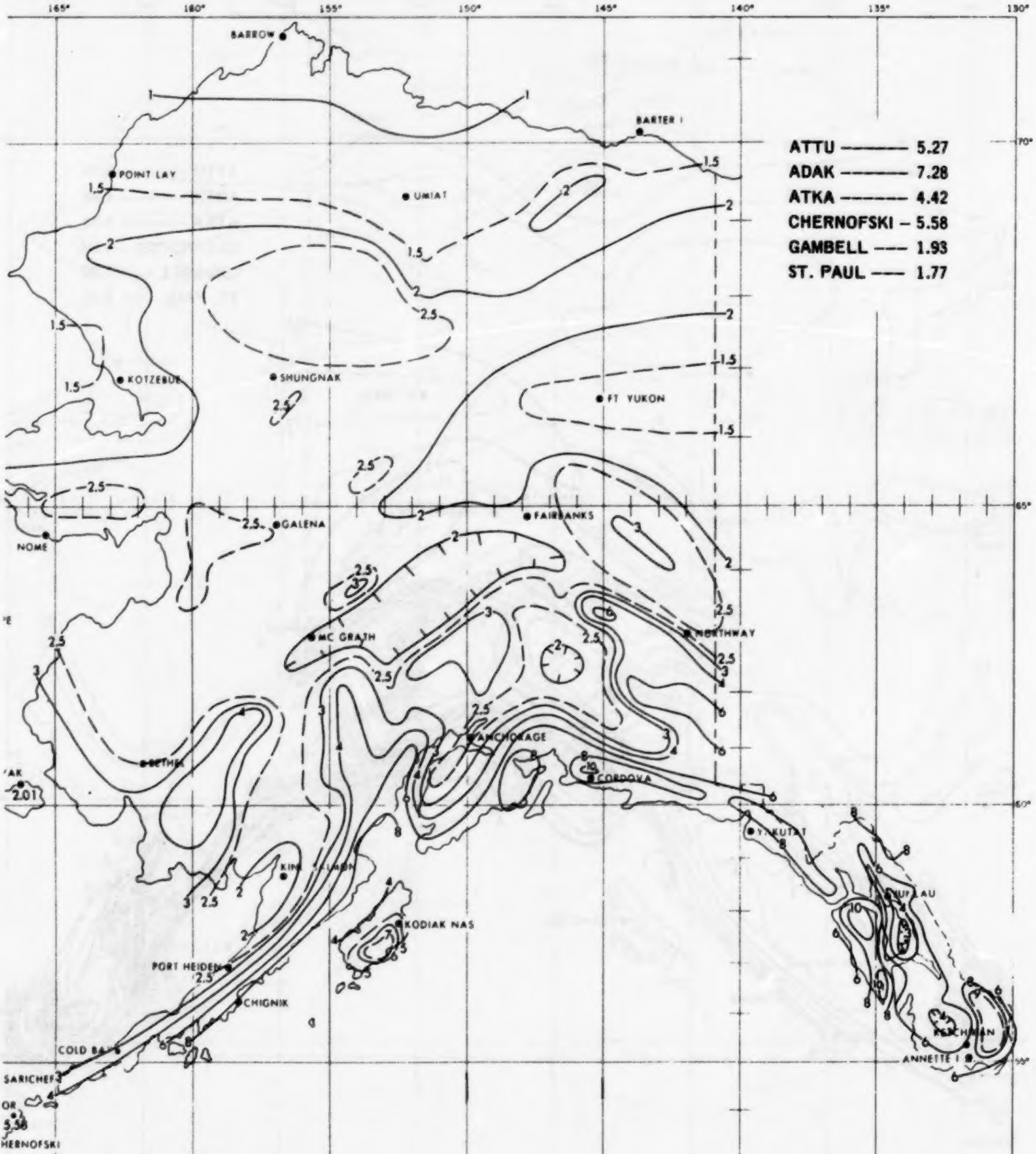

165°
160°
155°
150°
145°
140°
135°
130°
70°
65°
60°
55°
ATTU ——— 5.27
ADAK ——— 7.28
ATKA ——— 4.42
CHERNOFSKI – 5.58
GAMBELL — 1.93
ST. PAUL — 1.77
BARROW
BARTER I
POINT LAY
UMIAT
KOTZEBUE
SHUNGNAK
FT YUKON
FAIRBANKS
NOME
GALENA
MC GRATH
NORTHWAY
ANCHORAGE
CORDOVA
BETHEL
YAKUTAT
KING SALMON
KODIAK NAS
PORT HEIDEN
CHIGNIK
COLD BAY
SARICHEF
CHERNOFSKI
5.58
2.01
JUNEAU
KETCHIKAN
ANNETTE I
1
1.5
2
2.5
3
4
6
8
10

Exhibit 2-4
Sheet 3 of 5

Prepared from U. S. Weather
Bureau Maps

ALASKA

25-YEAR 24-HOUR RAINFALL (INCHES)

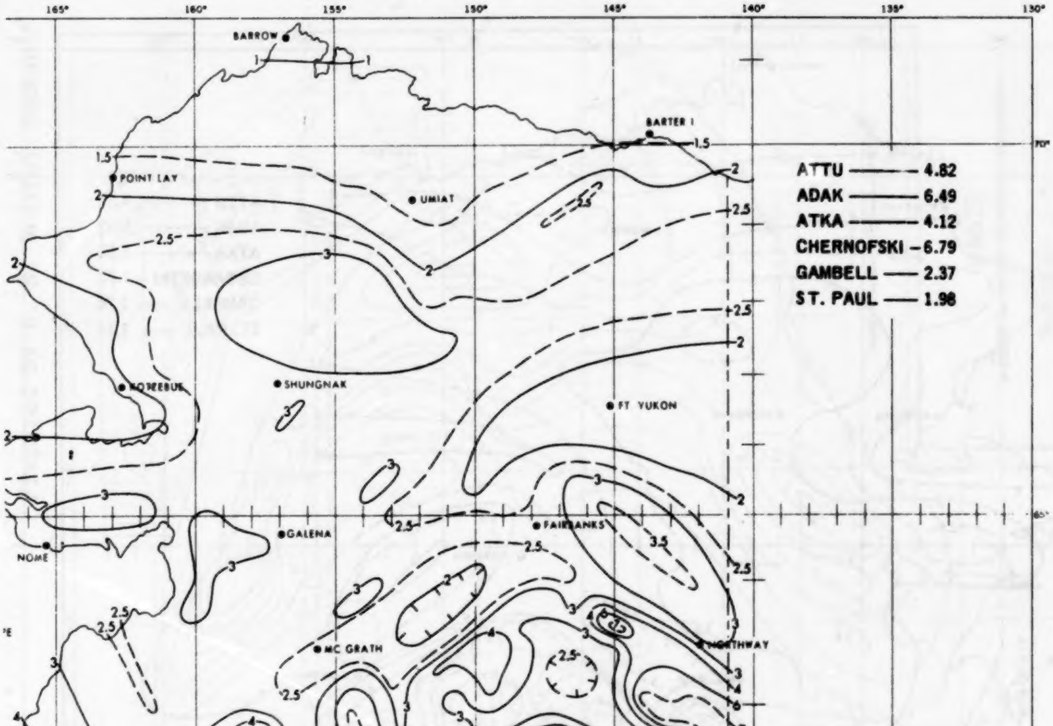
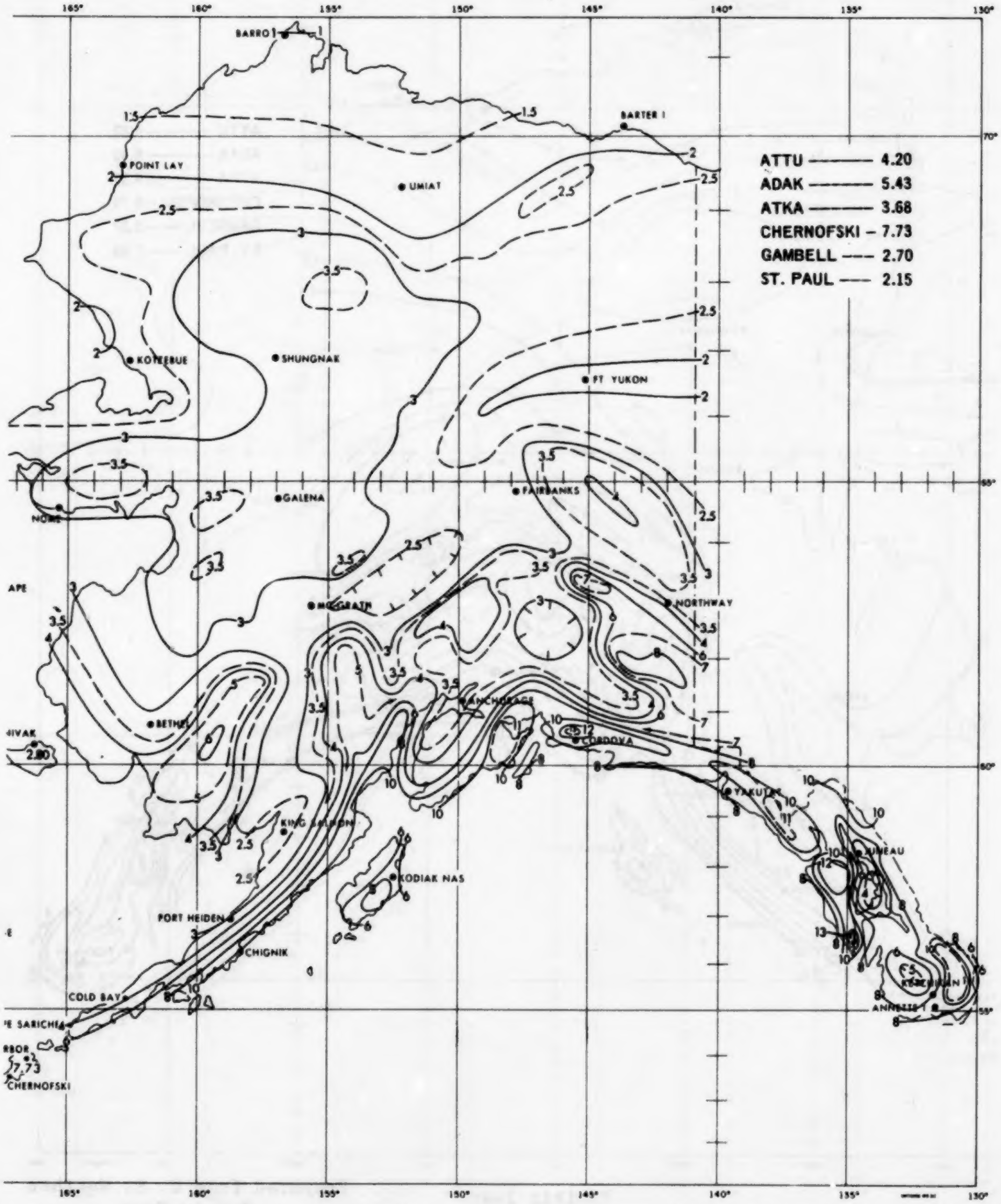

165°
160°
155°
150°
145°
140°
135°
130°
70°
65°
60°
55°
BARROW
BARTER I
POINT LAY
UMIAT
KOTZEBUE
SHUNGNAK
FT. YUKON
NOME
GALENA
FAIRBANKS
MC GRATH
NORTHWAY
BETHEL
ANCHORAGE
CORDOVA
YAKUTAT
JUNEAU
KING SALMON
KODIAK NAS
PORT HEIDEN
CHIGNIK
COLD BAY
SARICHEF
KETCHIKAN
ANNETTE I
CHERNOFSKI
6.79
2.51
ATTU — 4.82
ADAK — 6.49
ATKA — 4.12
CHERNOFSKI - 6.79
GAMBELL — 2.37
ST. PAUL — 1.98
1
1.5
2
2.5
3
3.5
4
5
6
7
8
10
12

Exhibit 2-4
Sheet 4 of 5

Prepared from U. S. Weather Bureau Maps

ALASKA

50-YEAR 24-HOUR RAINFALL (INCHES)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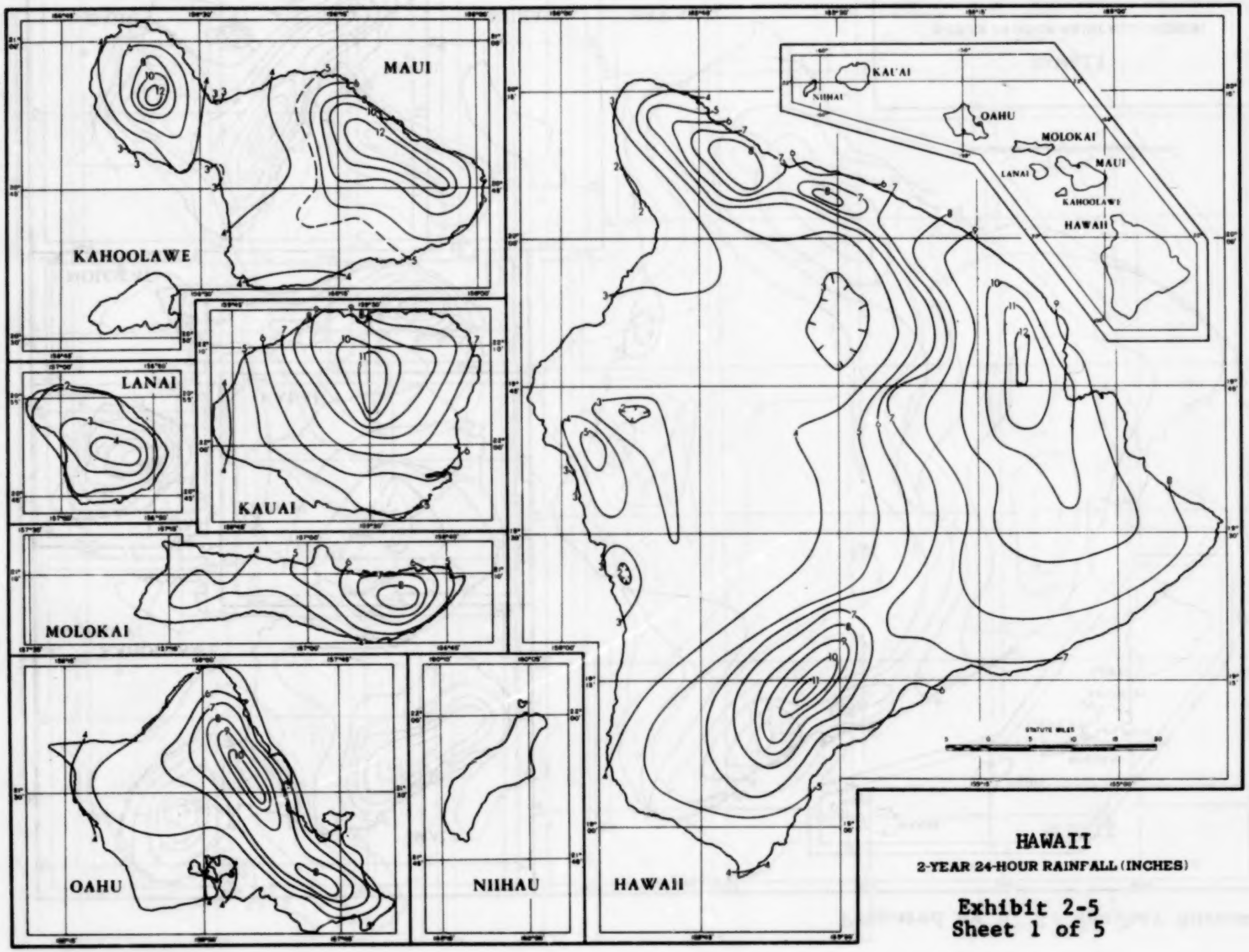
ADAK — 5.43
ATKA — 3.68
CHERNOFSKI - 7.73
GAMBELL — 2.70
ST. PAUL — 2.15
BARROW
BARTER I
POINT LAY
UMIAT
KOTZEBUE
SHUNGNAK
FT YUKON
NOME
GALENA
FAIRBANKS
MCGRATH
NORTHWAY
BETHEL
ANCHORAGE
CORDOVA
YAKUTAT
JUNEAU
KING SALMON
KODIAK NAS
PORT HEIDEN
CHIGNIK
COLD BAY
KETCHIKAN
ANNETTE I
CHERNOFSKI
7.73
2.80
165°
160°
155°
150°
145°
140°
135°
130°
70°
65°
60°
55°

Exhibit 2-4
Sheet 5 of 5

Prepared from U. S. Weather Bureau Maps

Prepared by U. S. Weather Bureau

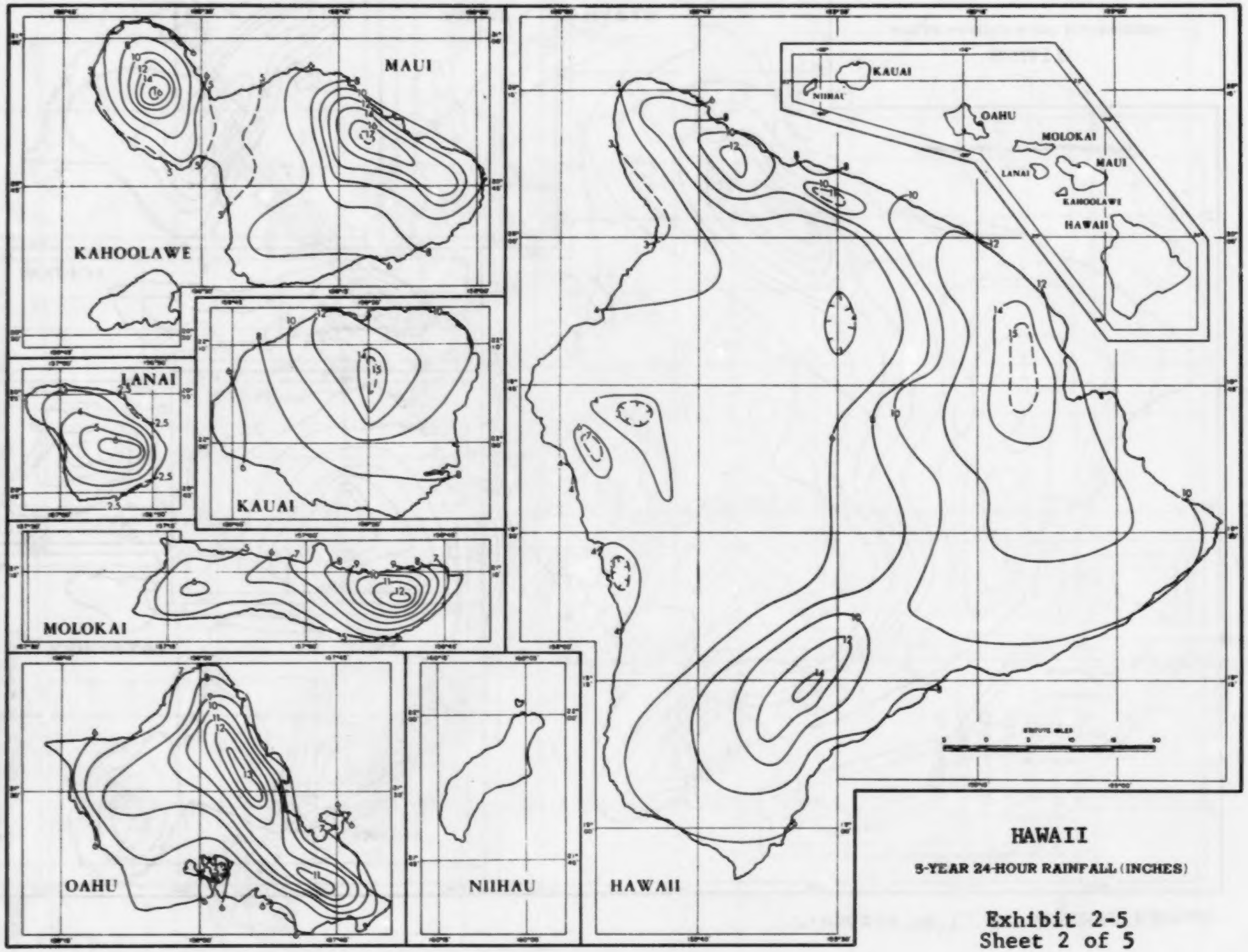

MAUI
KAHOOLAWE
LANAI
KAUAI
MOLOKAI
OAHU
NIIHAU
HAWAII
KAU'AI
NIIHAU
OAHU
MOLOKAI
LANAI
MAUI
KAHOOLAWE
HAWAII
STATUTE MILES

HAWAII

2-YEAR 24-HOUR RAINFALL (INCHES)

Exhibit 2-5
Sheet 1 of 5

Prepared by U. S. Weather Bureau

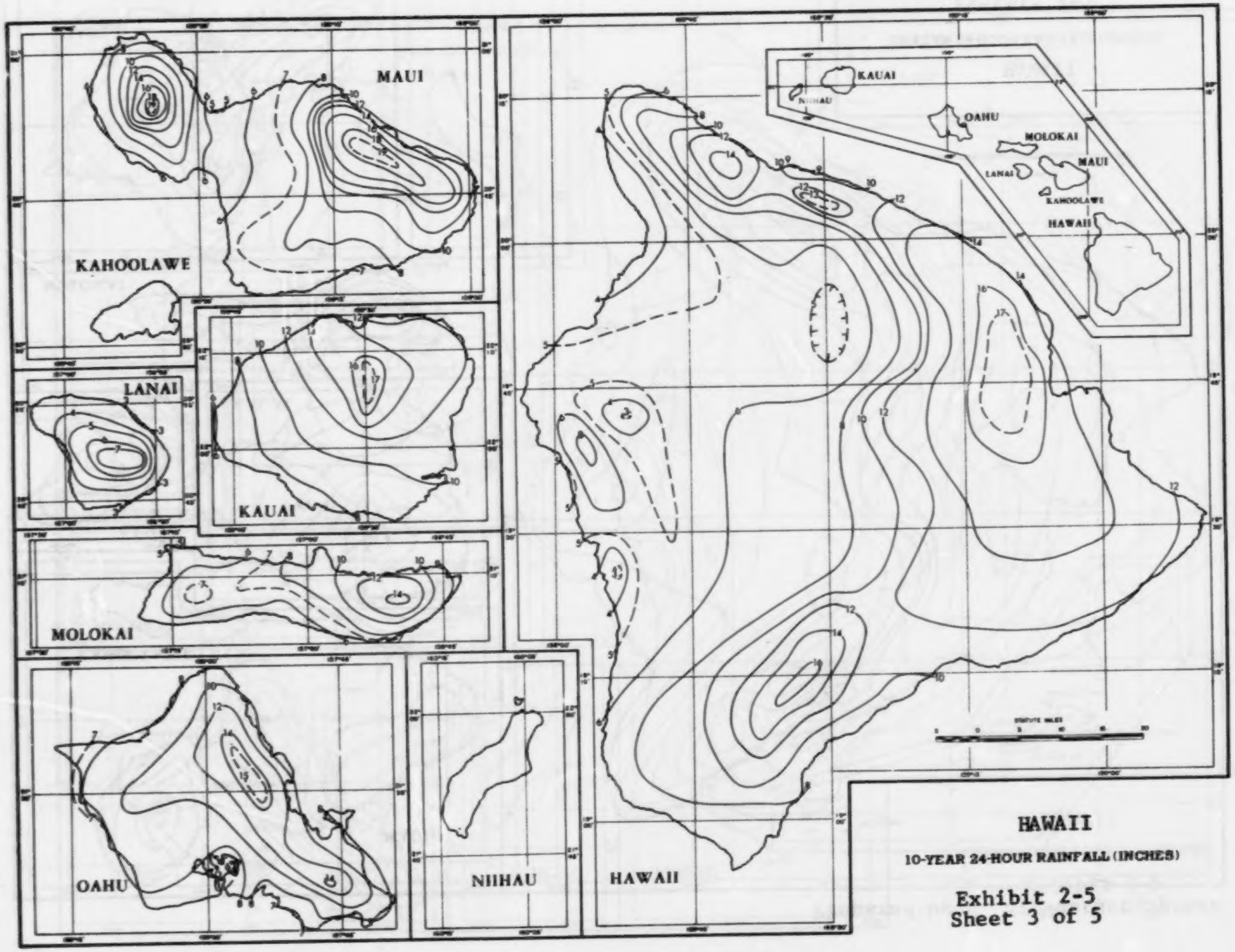

MAUI
KAHOOLAWE
LANAI
KAUAI
MOLOKAI
OAHU
NIIHAU
HAWAII
KAUAI
NIIHAU
OAHU
MOLOKAI
LANAI
MAUI
KAHOOLAWE
HAWAII
STATUTE MILES

HAWAII

5-YEAR 24-HOUR RAINFALL (INCHES)

Exhibit 2-5
Sheet 2 of 5

Prepared by U. S. Weather Bureau

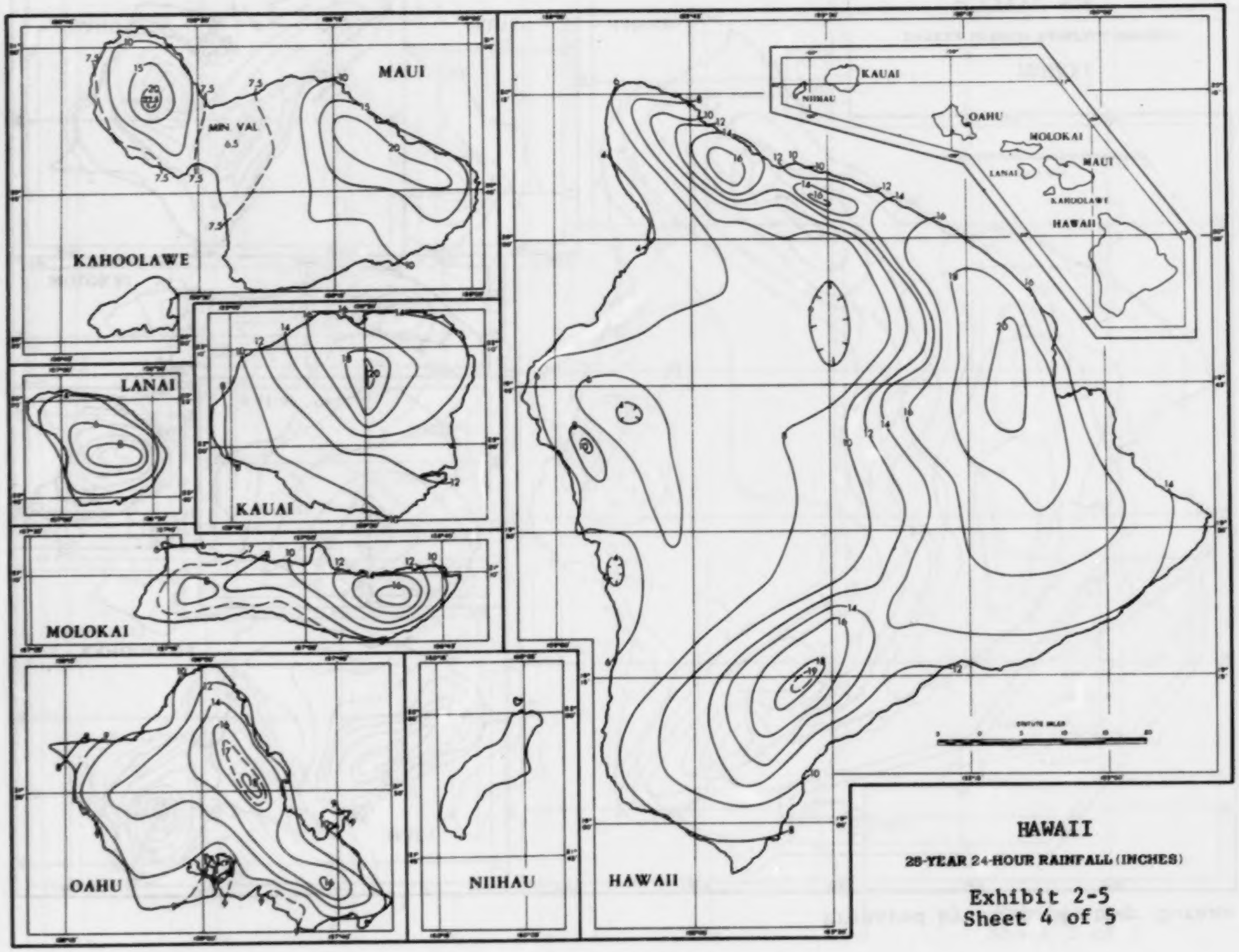

MAUI
KAHOOLAWE
LANAI
KAUAI
MOLOKAI
OAHU
NIIHAU
HAWAII
KAUAI
NIIHAU
OAHU
MOLOKAI
LANAI
MAUI
KAHOOLAWE
HAWAII
STATUTE MILES

HAWAII

10-YEAR 24-HOUR RAINFALL (INCHES)

Exhibit 2-5
Sheet 3 of 5

Prepared by U. S. Weather Bureau


MAUI
MIN VAL
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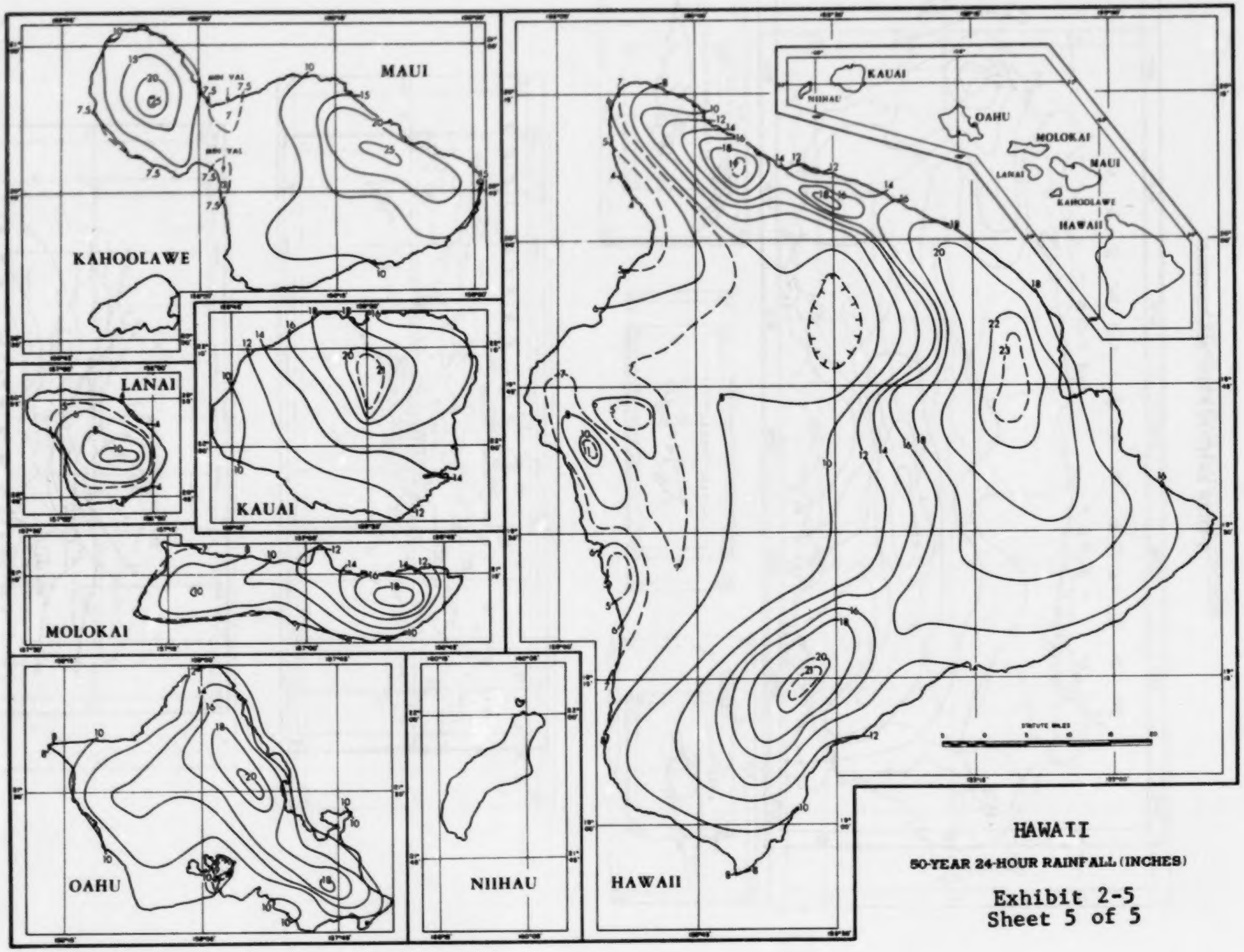
KAHOOLAWE
LANAI
KAUAI
MOLOKAI
OAHU
NIIHAU
HAWAII
KAUAI
NIIHAU
OAHU
MOLOKAI
MAUI
LANAI
KAHOOLAWE
HAWAII
STATUTE MILES

HAWAII

28-YEAR 24-HOUR RAINFALL (INCHES)

Exhibit 2-5
Sheet 4 of 5

Prepared by U. S. Weather Bureau


KAUAI
NIIHAU
OAHU
MOLOKAI
LANAI
MAUI
KAHOOLAWE
HAWAII
MAUI
KAHOOLAWE
LANAI
KAUAI
MOLOKAI
OAHU
NIIHAU
HAWAII
STATUTE MILES

HAWAII

50-YEAR 24-HOUR RAINFALL (INCHES)

Exhibit 2-5
Sheet 5 of 5

PUERTO RICO AND VIRGIN ISLANDS

2-YEAR 24-HOUR RAINFALL (INCHES)

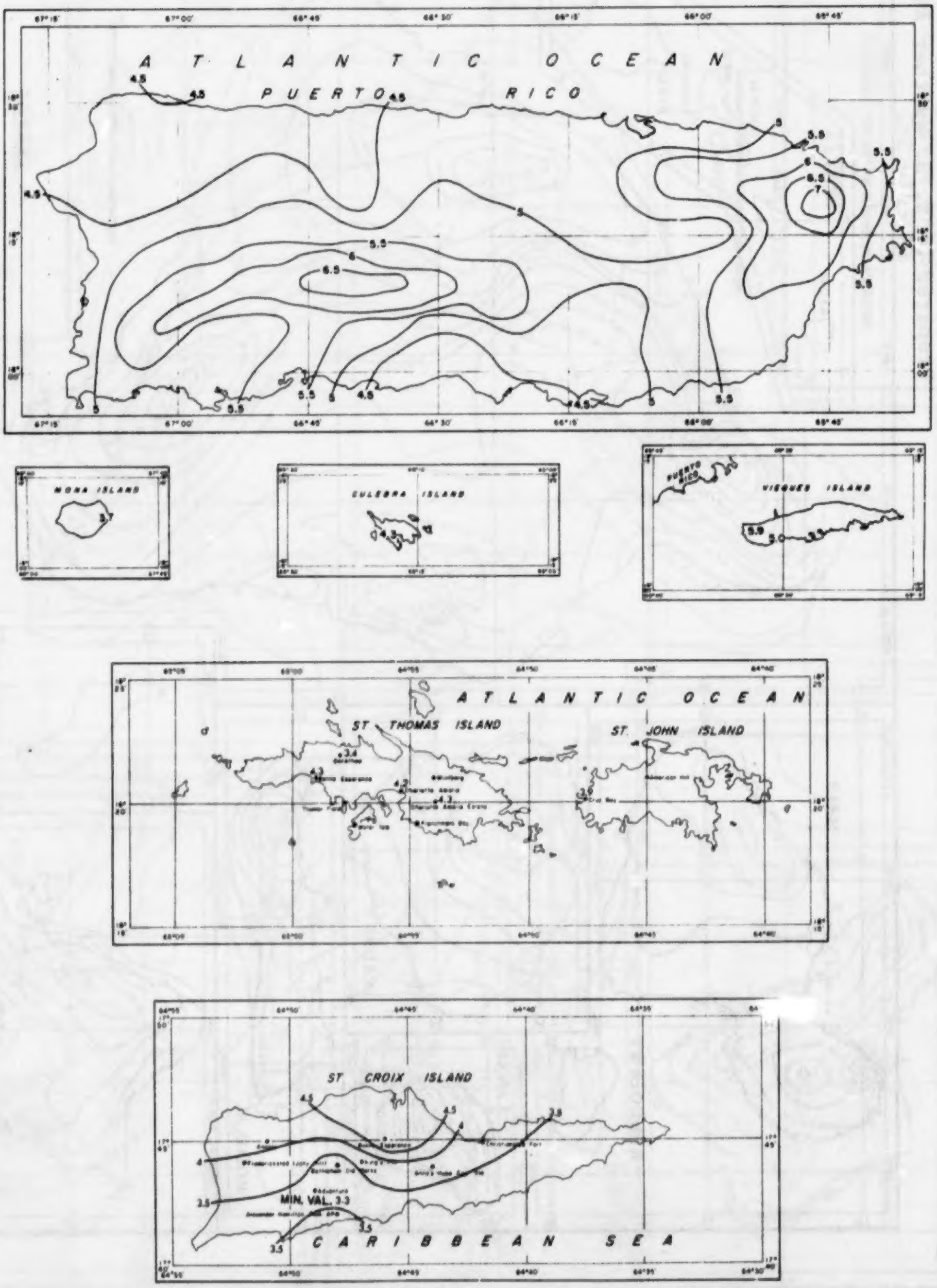
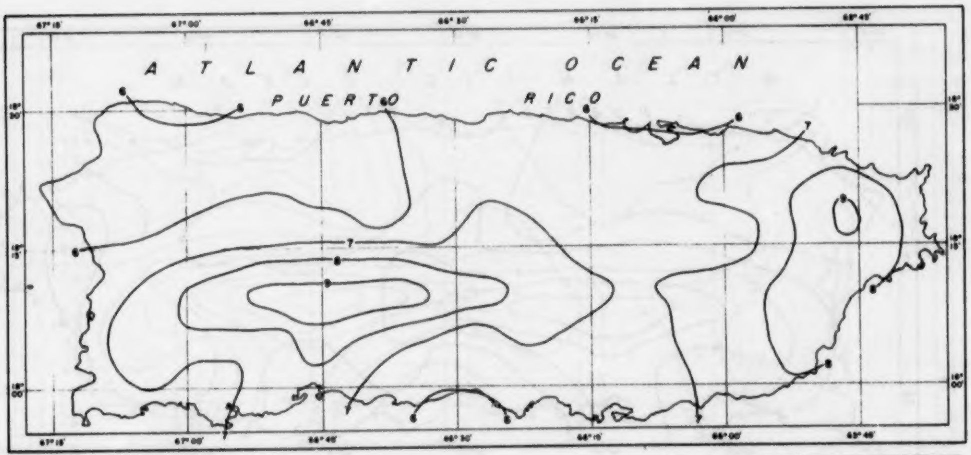

ATLANTIC OCEAN
PUERTO RICO
4.5
5
5.5
6
6.5
7
MONA ISLAND
3.7
CULEBRA ISLAND
4.5
PUERTO RICO
VIEQUES ISLAND
5.5
5.0
ATLANTIC OCEAN
ST. THOMAS ISLAND
ST. JOHN ISLAND
3.4
4.3
4.2
4.3
ST CROIX ISLAND
4.5
4
3.5
MIN. VAL. 3.3
CARIBBEAN SEA

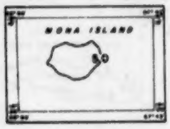
Exhibit 2-6
Sheet 1 of 5

Prepared from U. S. Weather
Bureau Maps

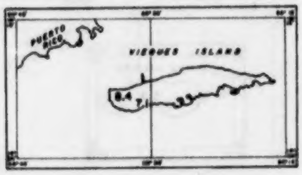
PUERTO RICO AND VIRGIN ISLANDS

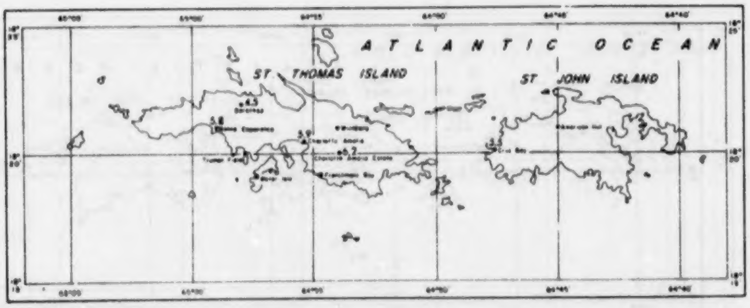
5-YEAR 24-HOUR RAINFALL (INCHES)


A T L A N T I C O C E A N
P U E R T O R I C O
6
7
8
9


MONA ISLAND
5.0

CULEBRA ISLAND


PUERTO RICO
VIEQUES ISLAND
6.4


A T L A N T I C O C E A N
ST THOMAS ISLAND
ST JOHN ISLAND
4.5
5.8
5.9
6.2
5.5

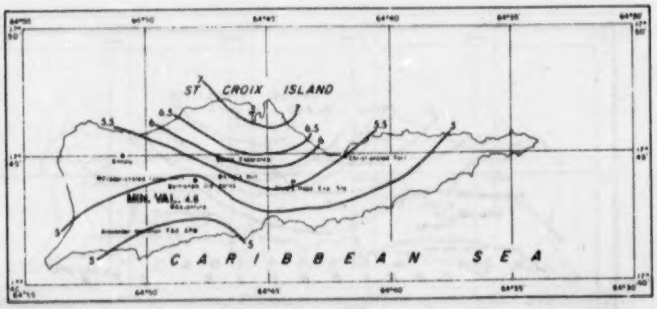

ST CROIX ISLAND
7
6.5
6
5.5
5
MIN. VAL. 4.8
C A R I B B E A N S E A

Exhibit 2-6
Sheet 2 of 5

Prepared from U. S. Weather
Bureau Maps

PUERTO RICO AND VIRGIN ISLANDS

10-YEAR 24-HOUR RAINFALL (INCHES)

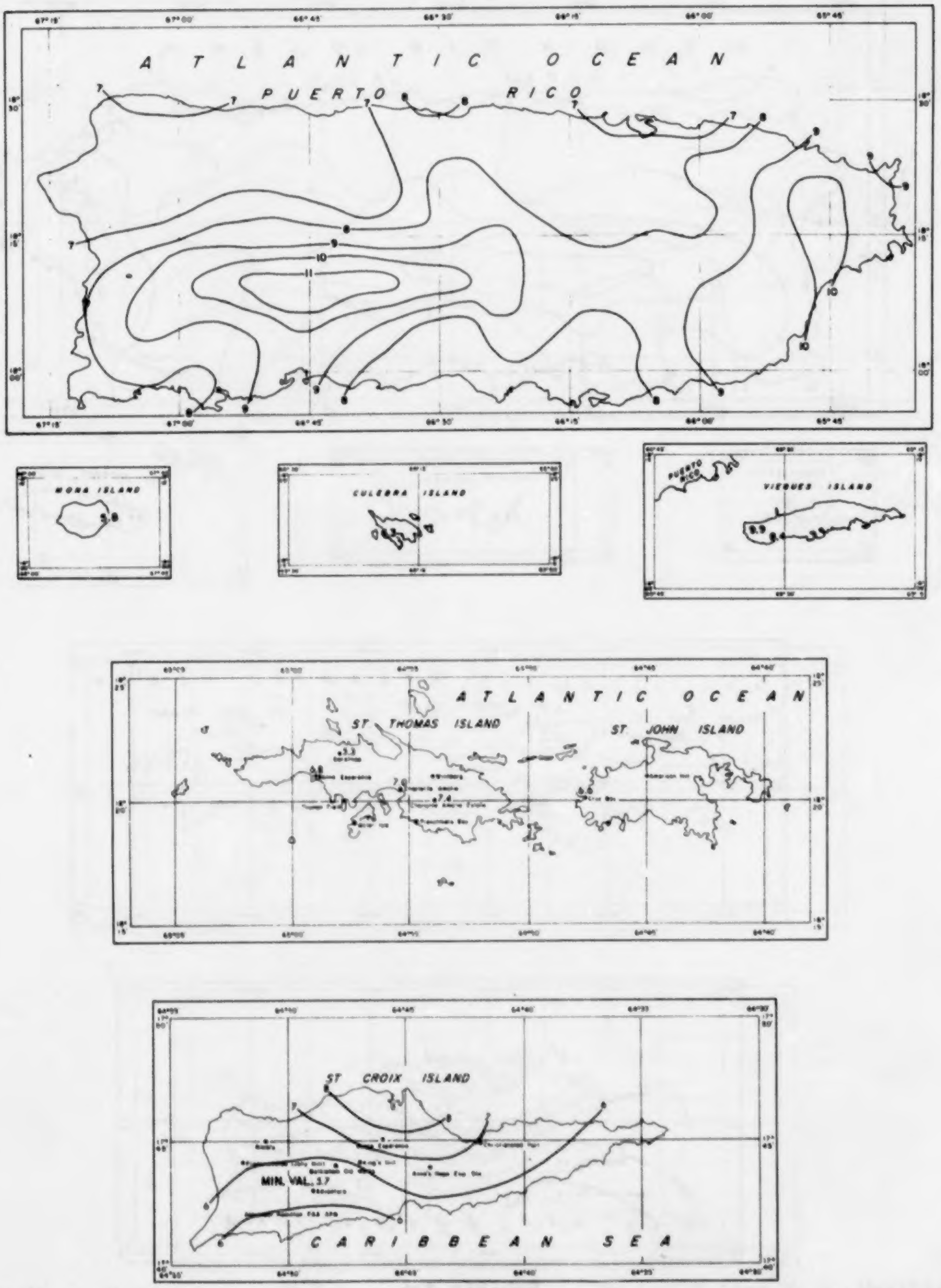
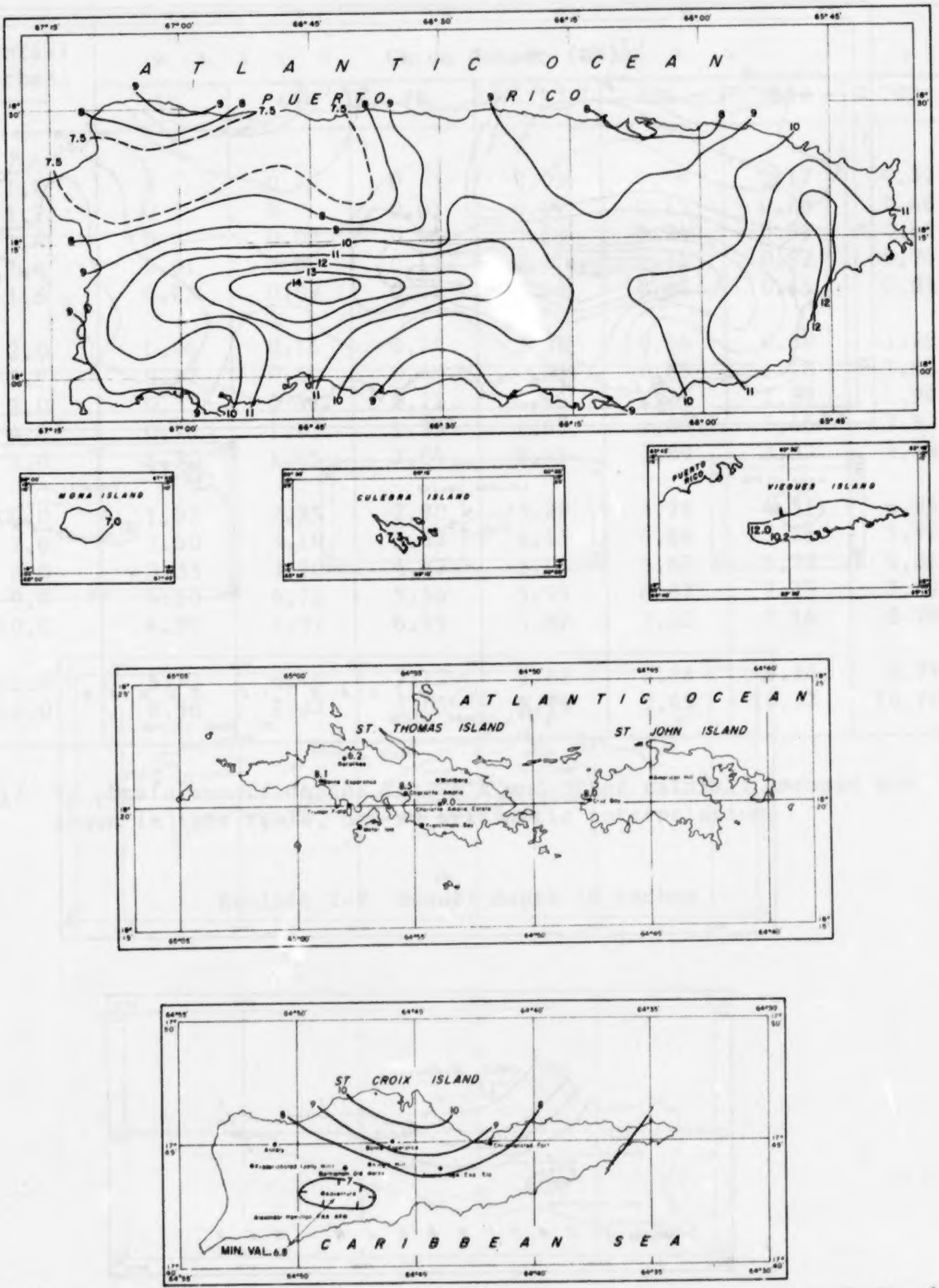

A T L A N T I C O C E A N
P U E R T O R I C O
7
8
9
10
11
MONA ISLAND
5.8
CULEBRA ISLAND
PUERTO RICO
VIEQUES ISLAND
9.9
A T L A N T I C O C E A N
ST THOMAS ISLAND
ST JOHN ISLAND
5.3
6.8
7.0
7.4
ST CROIX ISLAND
MIN. VAL. 5.7
C A R I B B E A N S E A

Exhibit 2-6
Sheet 3 of 5

Prepared from U. S. Weather
Bureau Maps

PUERTO RICO AND VIRGIN ISLANDS

25-YEAR 24-HOUR RAINFALL (INCHES)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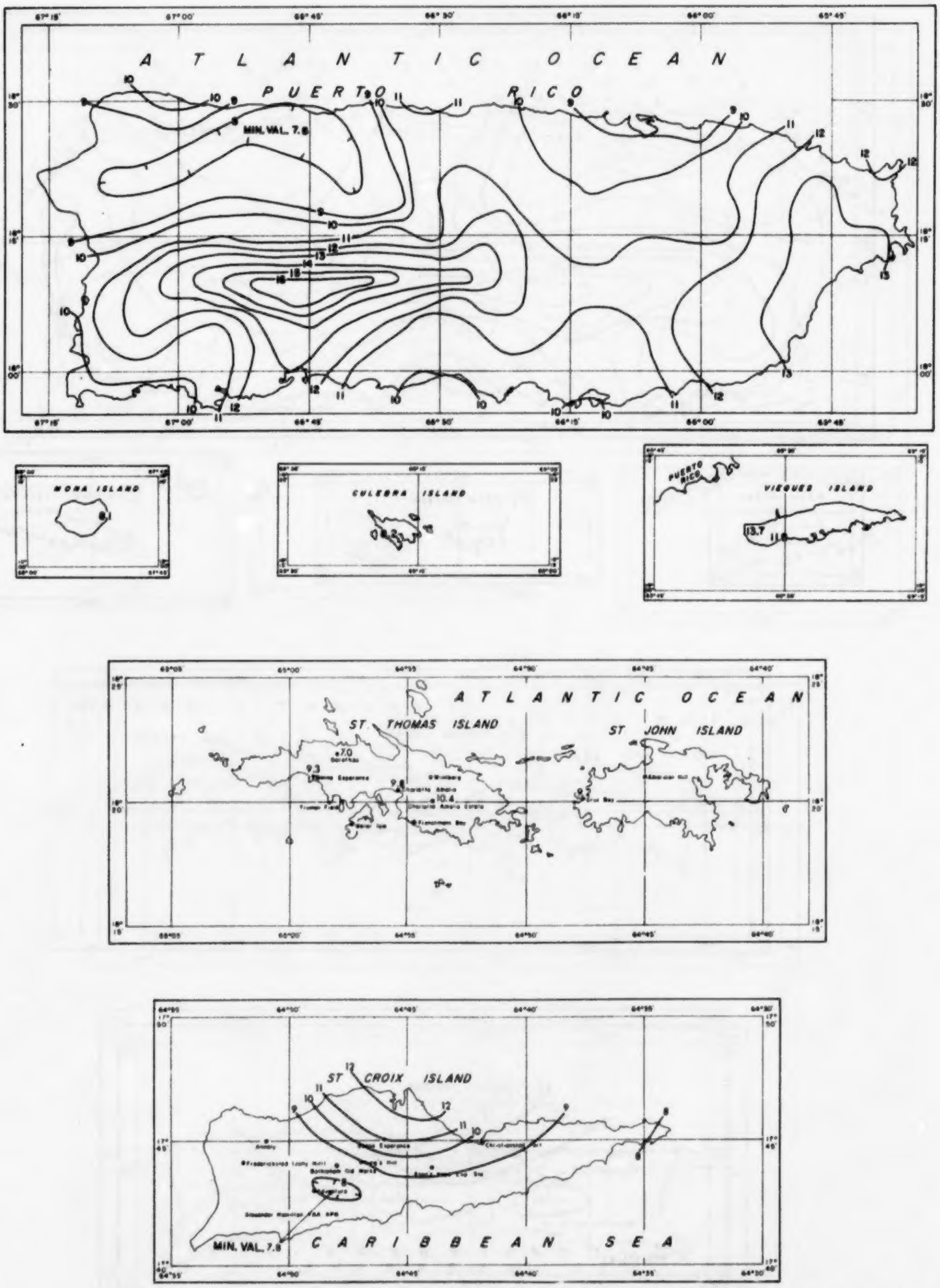
PUERTO RICO
MONA ISLAND
7.0
CULEBRA ISLAND
VIEQUES ISLAND
PUERTO RICO
12.0
10.2
ATLANTIC OCEAN
ST THOMAS ISLAND
ST JOHN ISLAND
ST CROIX ISLAND
CARIBBEAN SEA
MIN. VAL. 6.8

Exhibit 2-6
Sheet 4 of 5

Prepared from U. S. Weather
Bureau Maps

PUERTO RICO AND VIRGIN ISLANDS

50-YEAR 24-HOUR RAINFALL (INCHES)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PUERTO RICO
MIN. VAL. 7.8
MONA ISLAND
CULEBRA ISLAND
VIEQUES ISLAND
PUERTO RICO
13.7
ATLANTIC OCEAN
ST THOMAS ISLAND
ST JOHN ISLAND
7.0
9.3
9.8
10.4
ST CROIX ISLAND
MIN. VAL. 7.8
CARIBBEAN SEA

Exhibit 2-6
Sheet 5 of 5

Prepared from U. S. Weather
Bureau Maps

Rainfall (inches)	Curve Number (CN)[1]						
	60	65	70	75	80	85	90
1.0	0	0	0	0.03	0.08	0.17	0.32
1.2	0	0	0.03	0.07	0.15	0.28	0.46
1.4	0	0.02	0.06	0.13	0.24	0.39	0.61
1.6	0.01	0.05	0.11	0.20	0.34	0.52	0.76
1.8	0.03	0.09	0.17	0.29	0.44	0.65	0.93
2.0	0.06	0.14	0.24	0.38	0.56	0.80	1.09
2.5	0.17	0.30	0.46	0.65	0.89	1.18	1.53
3.0	0.33	0.51	0.72	0.96	1.25	1.59	1.98
4.0	0.76	1.03	1.33	1.67	2.04	2.46	2.92
5.0	1.30	1.65	2.04	2.45	2.89	3.37	3.88
6.0	1.92	2.35	2.80	3.28	3.78	4.31	4.85
7.0	2.60	3.10	3.62	4.15	4.69	5.26	5.82
8.0	3.33	3.90	4.47	5.04	5.62	6.22	6.81
9.0	4.10	4.72	5.34	5.95	6.57	7.19	7.79
10.0	4.90	5.57	6.23	6.88	7.52	8.16	8.78
11.0	5.72	6.44	7.13	7.82	8.48	9.14	9.77
12.0	6.56	7.32	8.05	8.76	9.45	10.12	10.76

[1] To obtain runoff depths for CN's and other rainfall amounts not shown in this table, use an arithmetic interpolation.

Exhibit 2-7 Runoff depth in inches

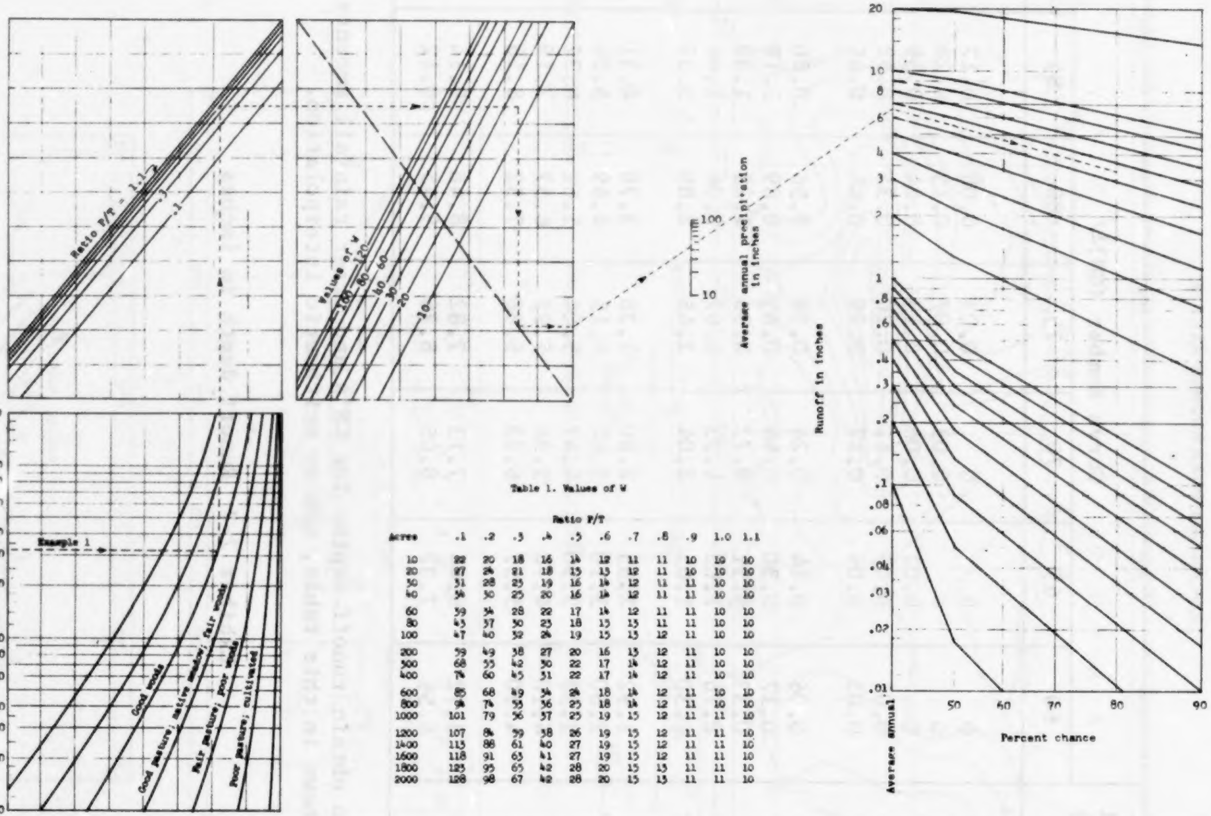

Table 1. Values of W

Acres	Ratio P/T .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1
10	22	20	18	16	14	12	11	11	10	10	10
20	27	24	21	18	15	13	12	11	10	10	10
30	31	28	23	19	16	14	12	11	11	10	10
40	34	30	25	20	16	14	12	11	11	10	10
60	39	34	28	22	17	14	12	11	11	10	10
80	43	37	30	23	18	15	13	11	11	10	10
100	47	40	32	24	19	15	13	12	11	10	10
200	59	49	38	27	20	16	13	12	11	10	10
300	68	55	42	30	22	17	14	12	11	10	10
400	74	60	45	31	22	17	14	12	11	10	10
600	85	68	49	34	24	18	14	12	11	10	10
800	94	74	53	36	25	18	14	12	11	10	10
1000	101	79	56	37	25	19	15	12	11	11	10
1200	107	84	59	38	26	19	15	12	11	11	10
1400	113	88	61	40	27	19	15	12	11	11	10
1600	118	91	63	41	27	19	15	12	11	11	10
1800	123	95	65	42	28	20	15	13	11	11	10
2000	128	98	67	42	28	20	15	13	11	11	10

REFERENCE

This drawing developed by Victor Mockus in cooperation with Tyler H. Quackenbush and H.O. Ogrosky, for discussion at the Soil Conservation Service irrigation engineers' meeting at Sarasota, Florida, November 17, 1958. Suggestions made at that meeting have been considered in making this revision.

U. S. DEPARTMENT OF AGRICULTURE
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ENGINEERING DIVISION

STANDARD DWG. NO.
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SHEET 1 OF 2
DATE 12-5-58

Exhibit 2-8 Estimation of annual water yields from ungaged watersheds of 10 to 2000 acres

LIMITATIONS - These are of two kinds. First, there are those that a State Conservation Engineer may wish to place on the use of ES-1014 in his state. Such limitations will not be discussed here.

Second, there are limitations in the equation used to develop ES-1014. Of these, the limitation on drainage area size is the most important. It is easy enough to extend any of the scales on ES-1014, but extension of the drainage area scales may give you very misleading results. The size and direction (plus or minus) of the error becomes more uncertain the farther you go outside the limits of 10 to 2000 acres. The error is as bad at 1 acre as it is at 20,000 acres.

Another limitation on the use of ES-1014 is due to the simplified treatment of watershed cover, and to the omission of watershed soil differences. Some accuracy has been sacrificed in order to get a simple method. ES-1014 is not accurate enough for predicting what the effect of installing conservation practices will be.

ES-1014 does not take into account such things as irrigation return flow, unusual geologic effects on yield, or the effects of upstream reservoirs of any kind.

EXAMPLES - A pair of triangles and a sharp pencil will help in getting consistent results on ES-1014.

Example 1

Given: A watershed of 320 acres, all in woods in good hydrologic condition; average annual precipitation, 45 inches; average annual temperature, 64.5 degrees F.

What is the yield in AF for an 80 percent chance occurrence?

Solution: 1. Compute the ratio of precipitation to temperature, or P/T = 45/64.5 = 0.7. 2. In table 1 for P/T of 0.7 and 320 acres, find W = 14. 3. Enter the drawing at lower left with drainage area. Go across to curve marked "Good woods". Up to P/T ratio of 0.7. Across to W of 14 by interpolation. Down to turning line, then across to edge of graph. Connect this point with P of 45 inches on small scale and extend line to runoff scale. Read average annual runoff is 6.5 inches. Interpolate between lines and at 80 percent chance read runoff as 3.3 inches. This is the annual runoff that will be equalled or exceeded, on the average, for 80 of the years. 5. Get AF by computation:

$$\frac{\text{inches runoff}}{12}\text{ (acres)} = \text{AF} = \frac{3.3}{12}\text{ (320)} = 88\text{ AF}$$

Example 2

Given: A watershed of 500 acres with 400 acres in fair pasture and 100 acres in good woods; average annual precipitation, 45 inches; average annual temperatures, 64.5 degrees F.

What is the 80 percent chance yield in inches?

Solution: There are at least three different procedures for this case. The most direct will be given. 1. Compute the P/T ratio, or P/T = 0.7. 2. On table 1, find W = 14. 3. Enter with a drainage area of 500 acres and go across to a point interpolated between the "good woods" and "fair pasture" curves. This point is 400/500 of the distance between those two curves, toward the "fair pasture" curve. It is much closer to the "fair pasture" curve than to the "good woods" curve. Then up to P/T = 0.7. Across to W of 14 by interpolation. Down to turning line. Across to edge of graph. Connect this point with P of 45 inches on small scale and extend line to runoff scale. Read average annual runoff is 12.0 inches. Interpolate between lines and at 80 percent chance read runoff as 7.2 inches = answer.

DISCUSSION - Table 2 is a rough guide to the monthly distribution of runoff for selected localities. When a small watershed yields only surface runoff, the table values for that locality are more reliable than percents obtained from the record of a large stream or river.

The chart in the lower left of the drawing contains curves for which no cover is given. These curves are shown in order to permit further study in classifying watersheds.

The classifications of pasture (or range), and woods are taken from the Hydrology Guide (NEH-4-A), and are as follows:

Native pasture or range

Poor is heavily grazed, has no mulch; or has plant cover on less than about 50% of the area.

Fair has between 50 and 75% of the area with plant cover, and is not heavily grazed.

Good has more than about 75% of the area with plant cover and is lightly grazed.

Woods

Poor are heavily grazed or burned; no litter or brush.

Fair are grazed, but have some litter.

Good are protected; litter and shrubs cover the soil beneath the trees.

When making this drawing it was assumed the user would be more interested in yield from non-cultivated watersheds. An apparent increase in yield from cultivated watersheds may be more than offset by the increase of sediment caught in the reservoir. A few trials with the drawing will show you that the difference in yield between cultivated and non-cultivated watersheds decreases as watershed size increases, and ultimately only precipitation and temperature have any effect on yield.

Table 2. Monthly percents of the average annual yield for selected watersheds.

Watershed location	Area in acres	Years record	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Remarks
Arizona; Safford	723	14	0	0	0	0	0	0	46	38	12	4	0	0	Range
Arkansas; Bentonville	9	8	0	4	6	15	19	25	2	2	8	14	5	2	Pasture
California; Placerville	41	8	26	32	27	7	0	0	0	0	0	0	2	6	Orchard
Colorado; Colorado Spgs.	40	7	0	0	0	0	0	8	46	42	4	0	0	0	Plains. Range
Georgia; Watkinsville	19	16	16	10	15	12	5	5	9	11	1	2	10	8	Piedmont, cultivated
Idaho; Moscow	178	5	17	25	41	5	1	0	0	0	0	0	1	10	Plateau, prairie
Illinois; Edwardsville	290	17	9	11	14	15	10	11	8	9	1	3	5	4	50% cultivated
Nebraska; Hastings	481	17	0	1	5	5	14	37	18	5	13	5	1	0	Plains, cultivated
Ohio; Coshocton	44	16	12	12	22	18	14	7	2	1	2	1	3	6	Woods and brush
Oregon; Newburg	13	4	17	26	10	5	5	2	1	1	1	1	8	25	Orchard, 1500' elevation
Puerto Rico; Mayagüez	1/70*	9	2	0	0	0	4	5	11	21	26	15	12	4	Grass
Texas; Tyler	8	9	10	9	12	13	28	4	1	0	0	1	12	10	Wooded
Virginia; Staunton	590	6	8	9	9	16	14	11	8	6	3	13	3	0	Mixed cover (cult. 26%)
Wisconsin; Fennimore	330	17	8	11	16	6	6	12	12	10	6	5	4	4	Mixed cover

*Experimental plot with surface runoff only. For watersheds with base flow the percents will be more uniform.

REFERENCE

Percents on table 2 for the Puerto Rican location were computed from data in "Soil and Water Conservation Research in Puerto Rico, 1958 to 1947" University of Puerto Rico, Agri. Exp. Sta. Bul. 124. Percents for the other locations were computed from data in "Monthly Precipitation and Runoff for Small Agricultural Watersheds in the United States", a publication of the USDA Agricultural Research Service, Washington, D.C.

Exhibit 2-8

U. S. DEPARTMENT OF AGRICULTURE
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DATE 12-5-58

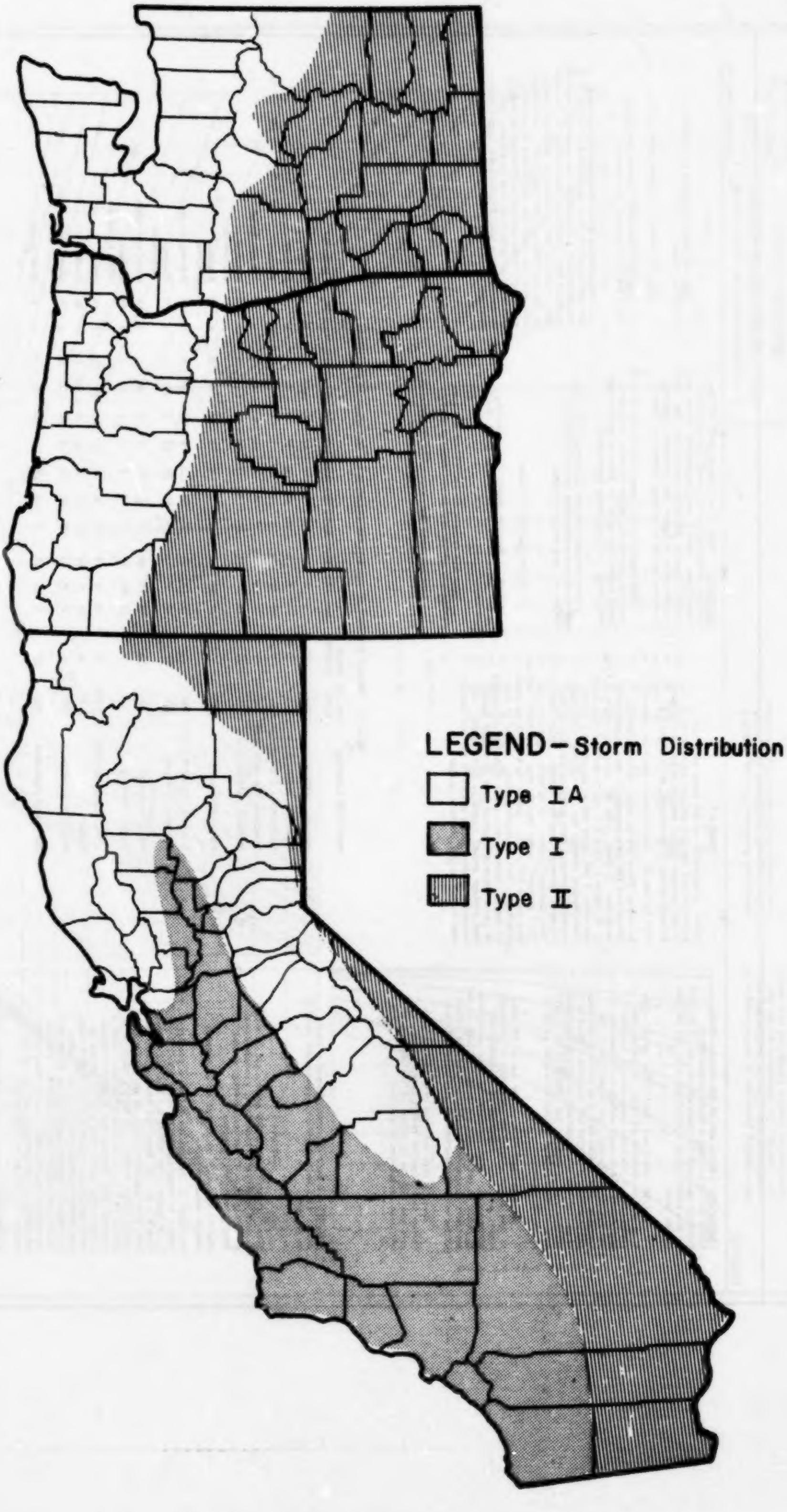
LEGEND - Storm Distribution
Type IA
Type I
Type II

Exhibit 2-9 Storm Distribution Regions, Pacific Coast States

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 60

24 HOUR RAINFALL FROM US WB TP-40

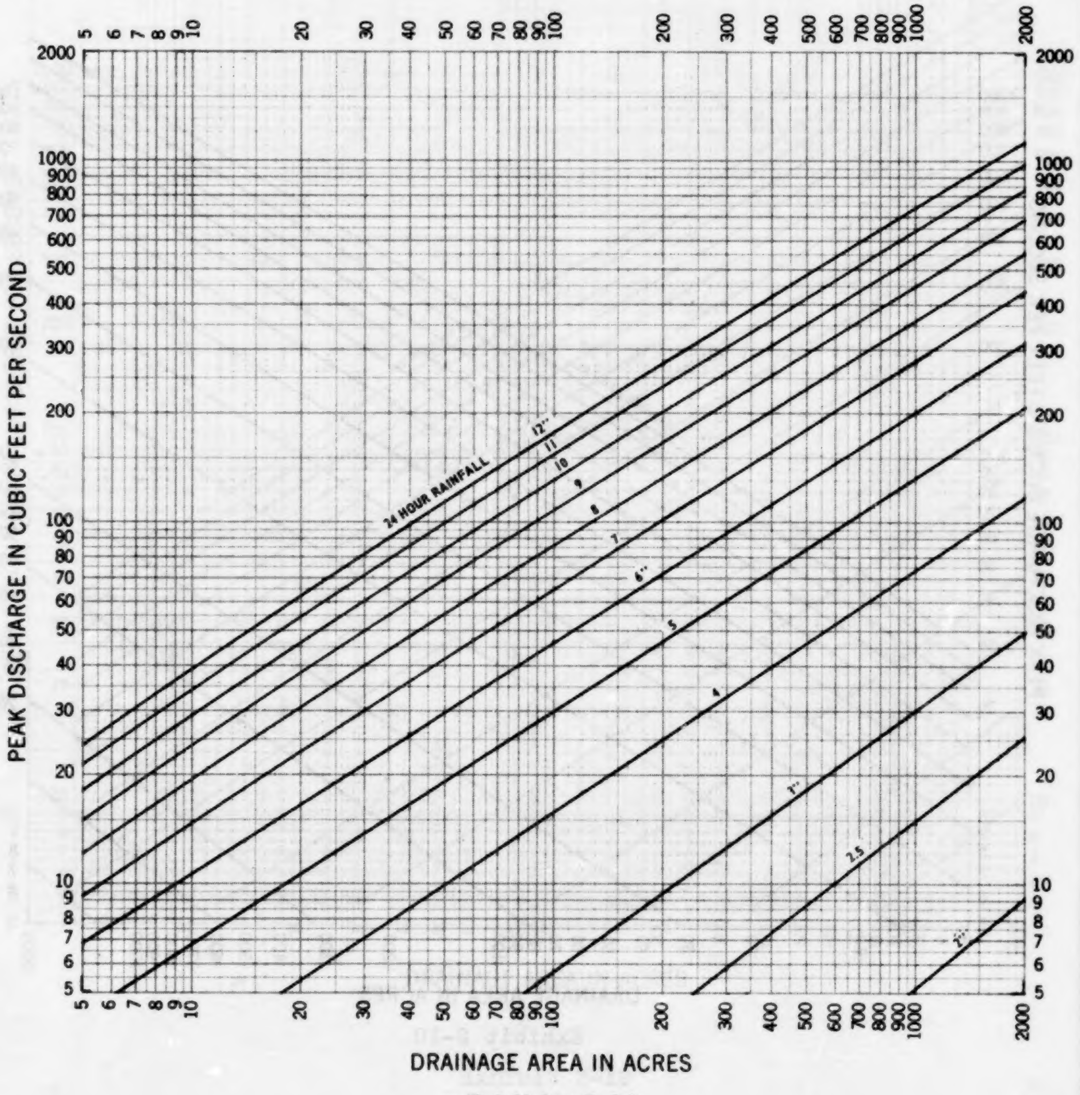

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual
for Conservation Practices"

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
SHEET 1 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 65

24 HOUR RAINFALL FROM US WB TP-40

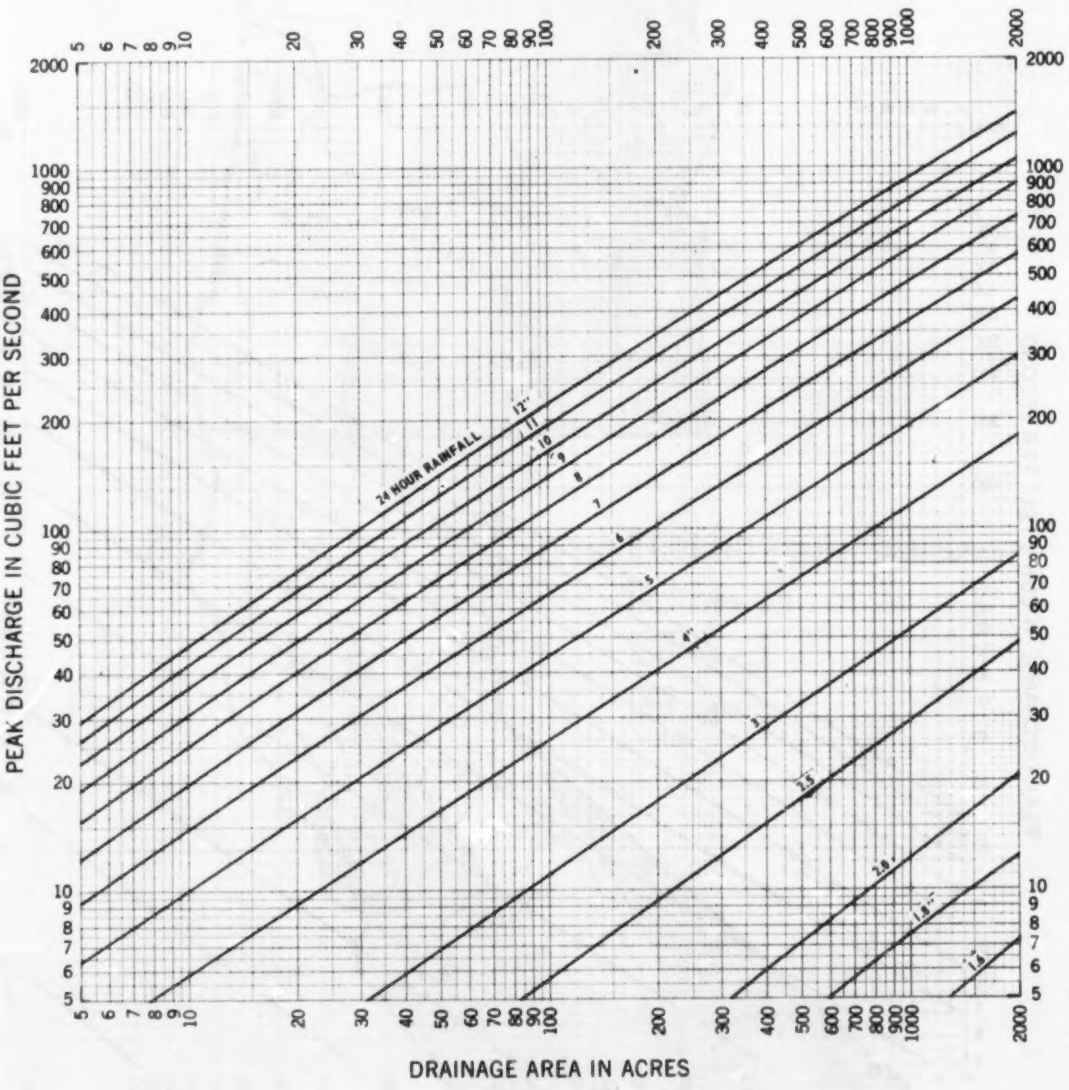

Exhibit 2-10

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 2 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS TYPE II STORM DISTRIBUTION

SLOPES - FLAT

CURVE NUMBER - 70

24 HOUR RAINFALL FROM US WB TP-40

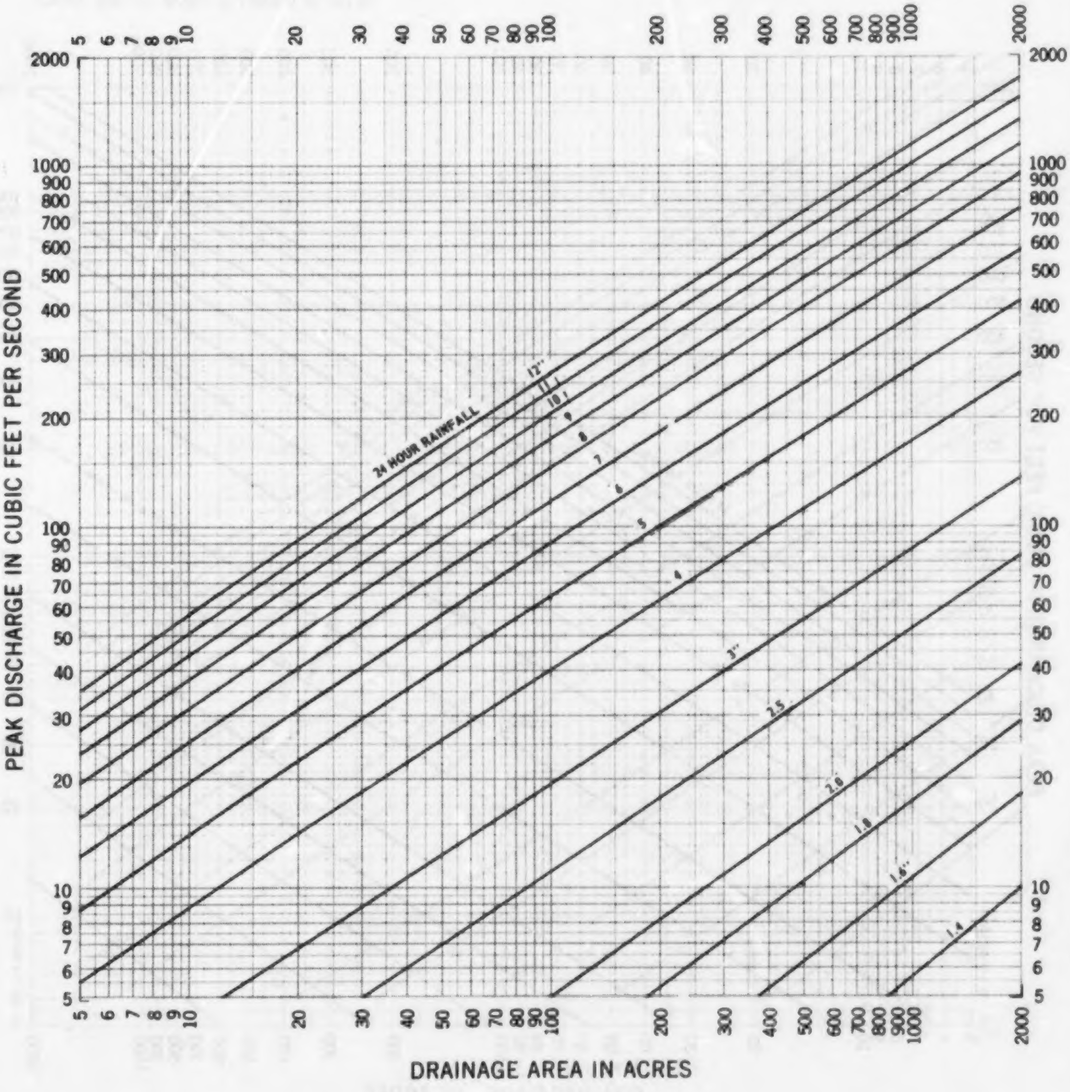

Exhibit 2-10

REFERENCE

"Chapter 2. Engineering Field Manual for Conservation Practices"

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ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
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DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 75

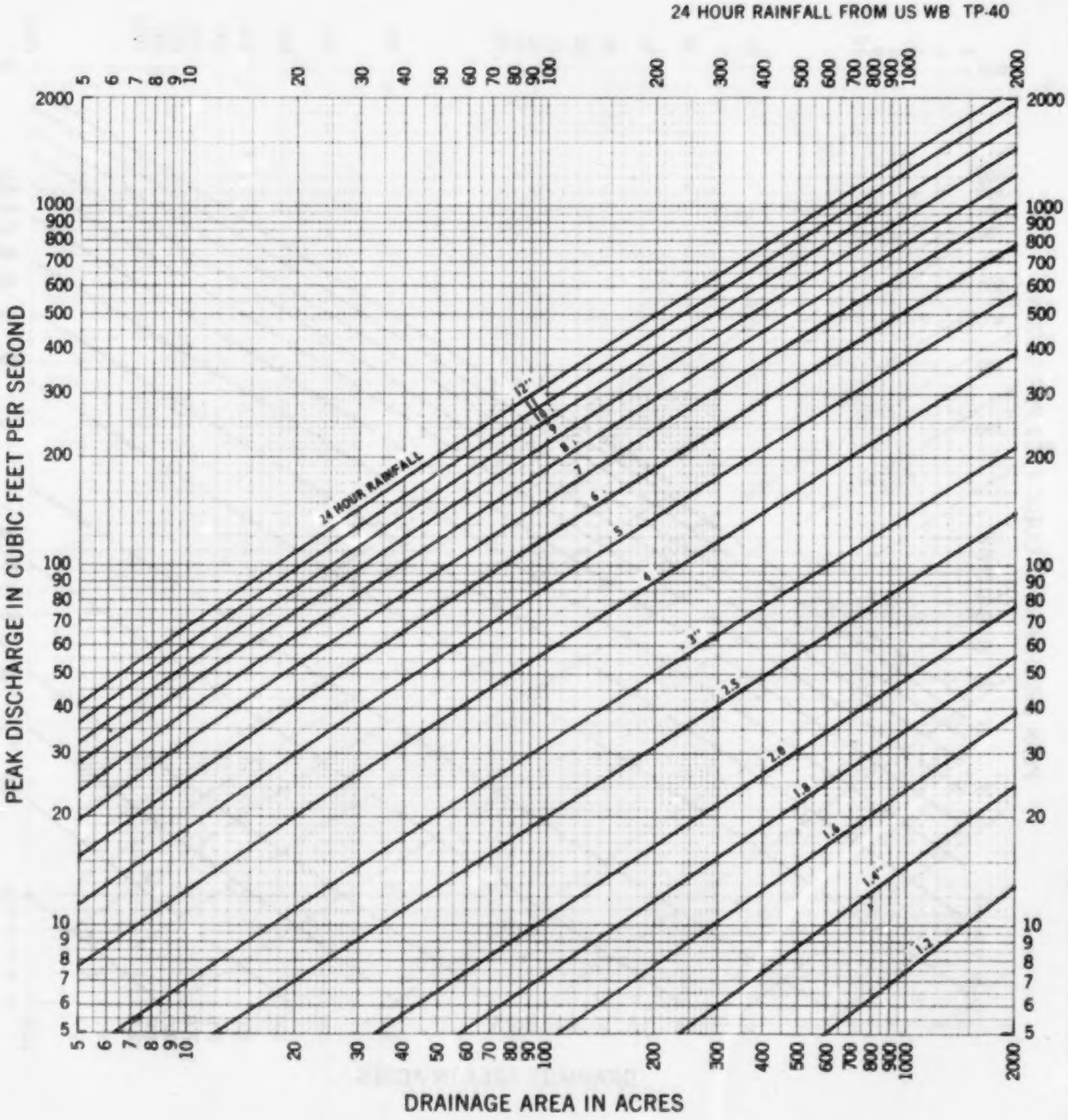

Exhibit 2-10

REFERENCE "Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	STANDARD DWG. NO. ES-1027 SHEET 4 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 80

24 HOUR RAINFALL FROM US WB TP-40

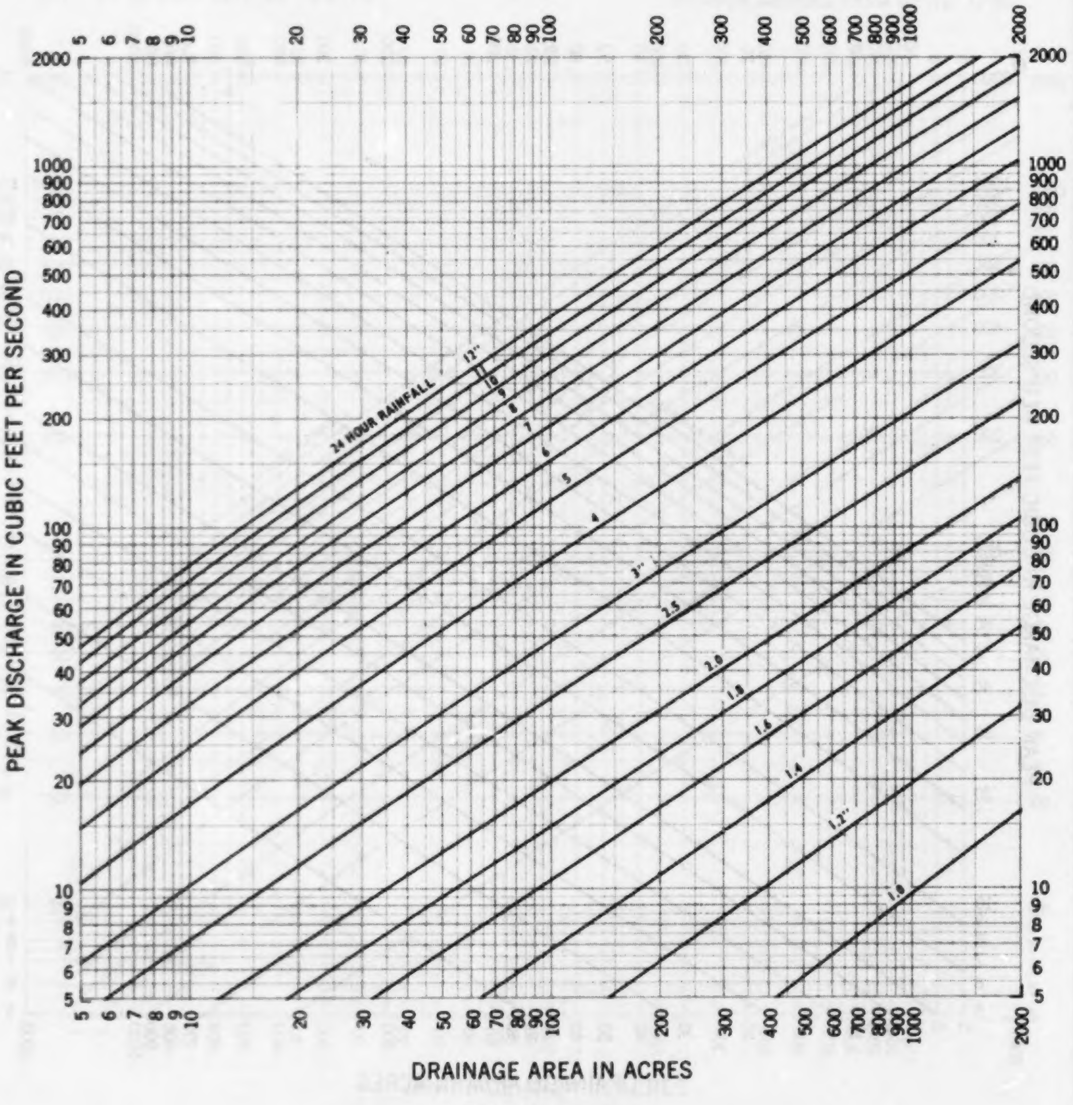

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual
for Conservation Practices"

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STANDARD DWG. NO.
ES-1027
SHEET 5 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 85

24 HOUR RAINFALL FROM US WB TP-40

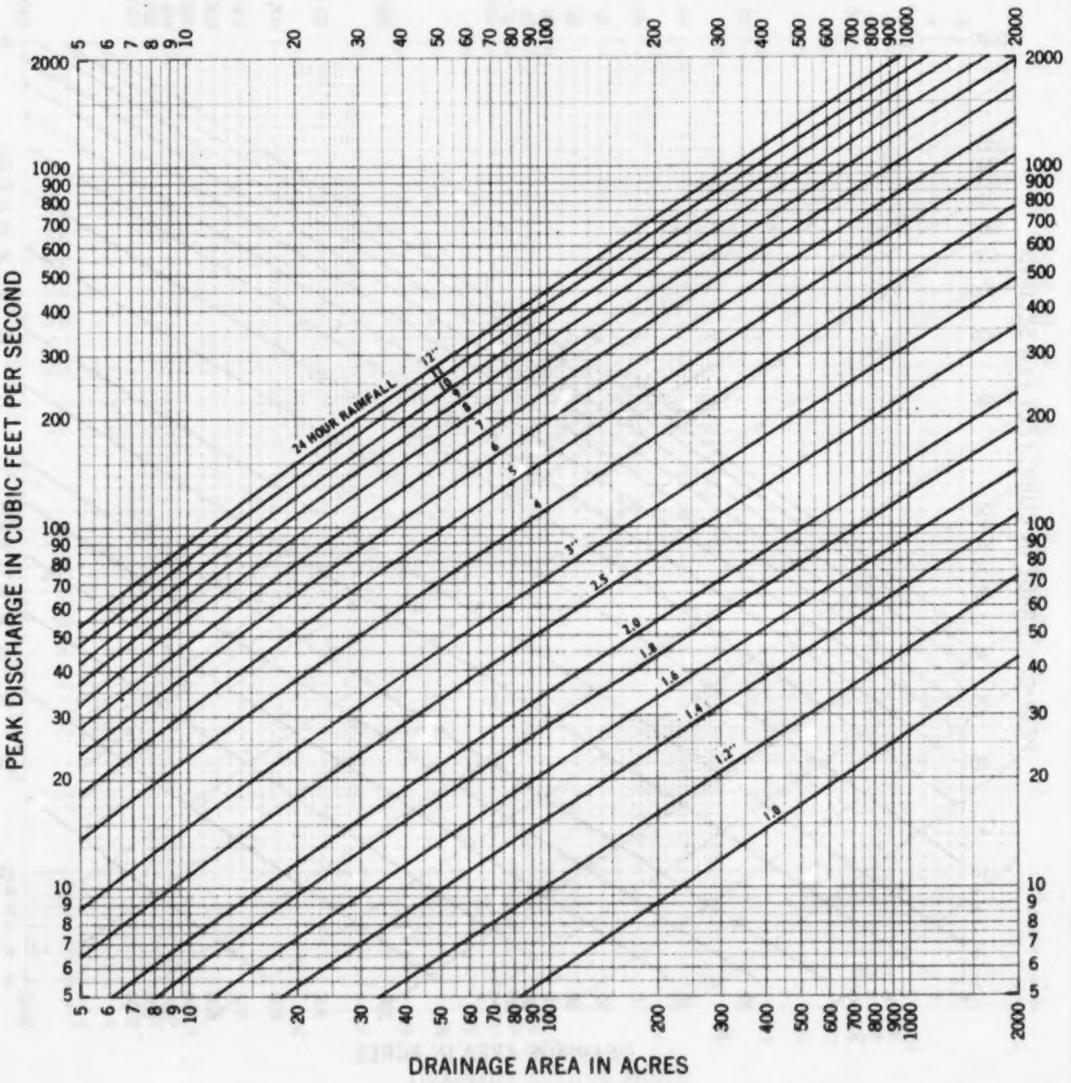

Exhibit 2-10

REFERENCE

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STANDARD DWG. NO.
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SHEET 6 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - FLAT
CURVE NUMBER - 90

24 HOUR RAINFALL FROM US WB TP-40

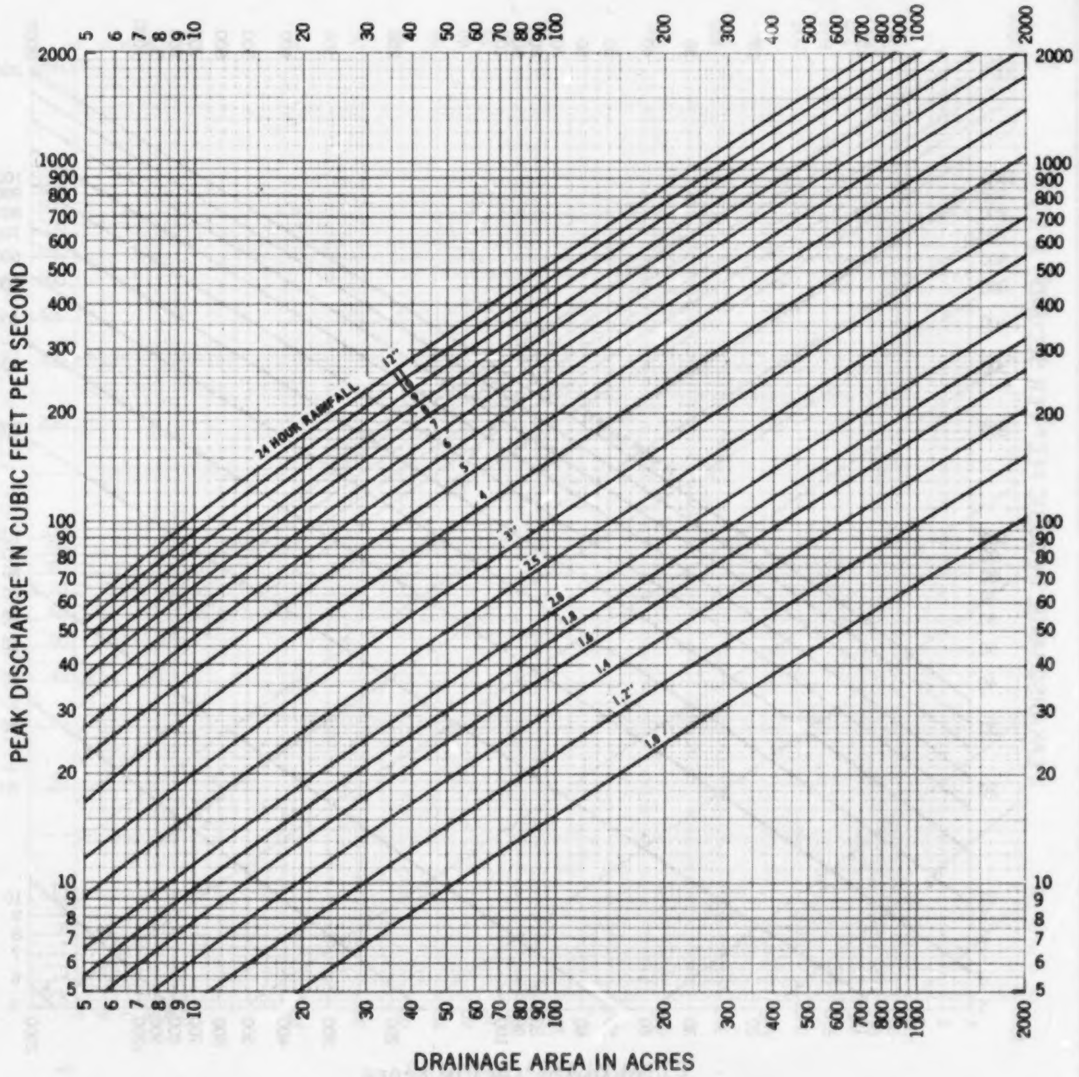

Exhibit 2-10

REFERENCE

"Chapter2 , Engineering Field Manual for Conservation Practices"

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STANDARD DWG. NO.
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SHEET 7 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 60

24 HOUR RAINFALL FROM US WB TP-40

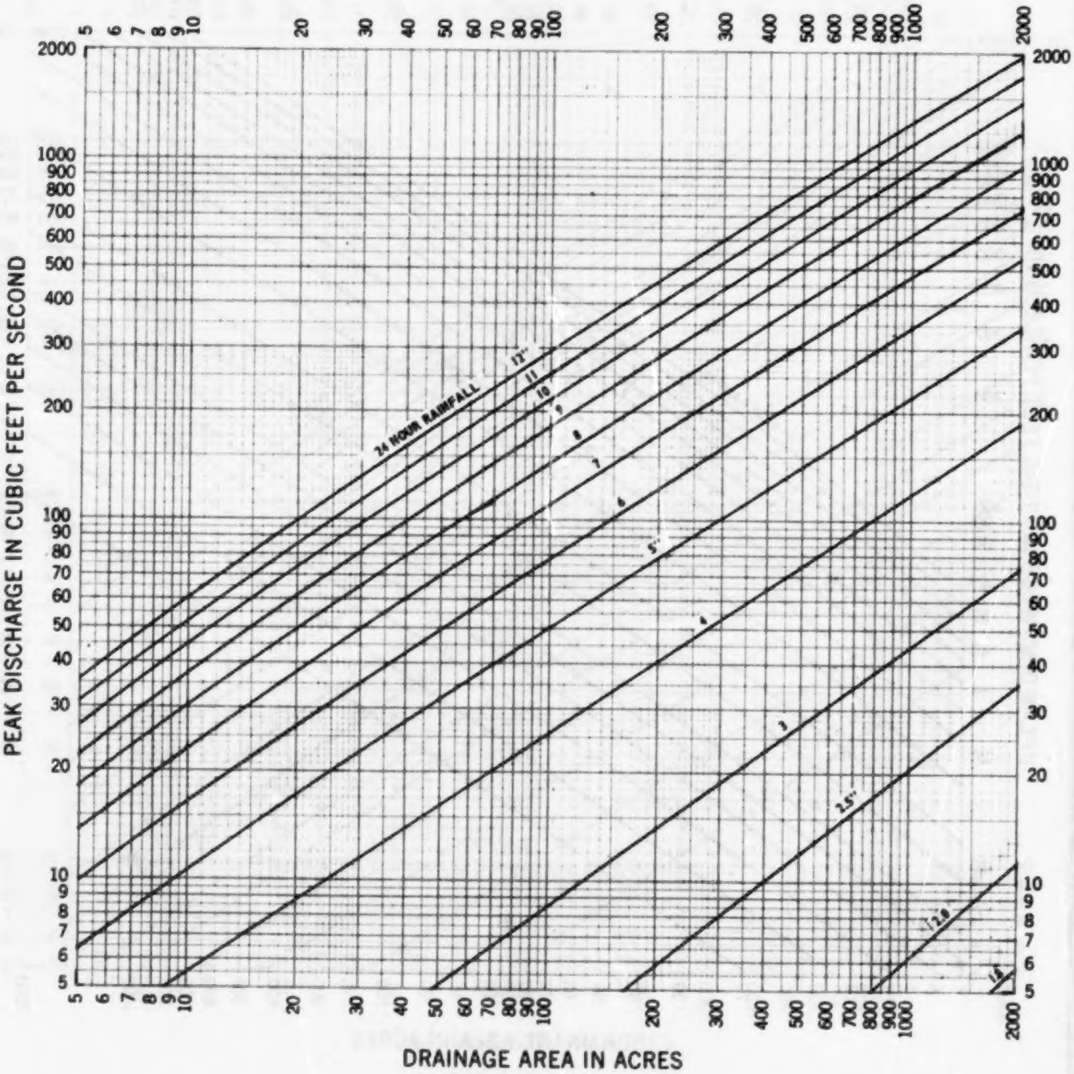

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual for Conservation Practices"

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ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
SHEET 8 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 65

24 HOUR RAINFALL FROM US WB TP-40

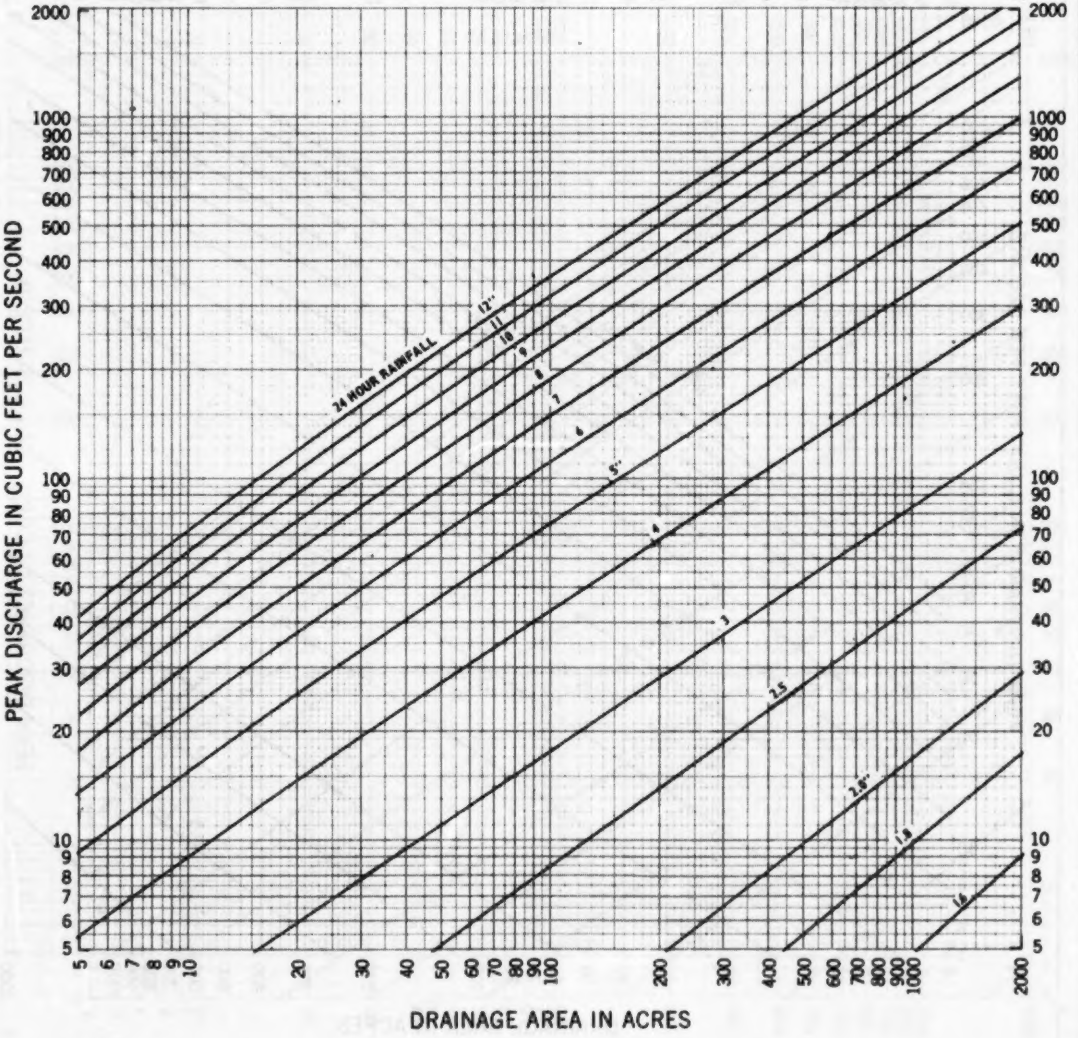

Exhibit 2-10

REFERENCE

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ENGINEERING DIVISION HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
SHEET 9 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 70

24 HOUR RAINFALL FROM US WB TP-40

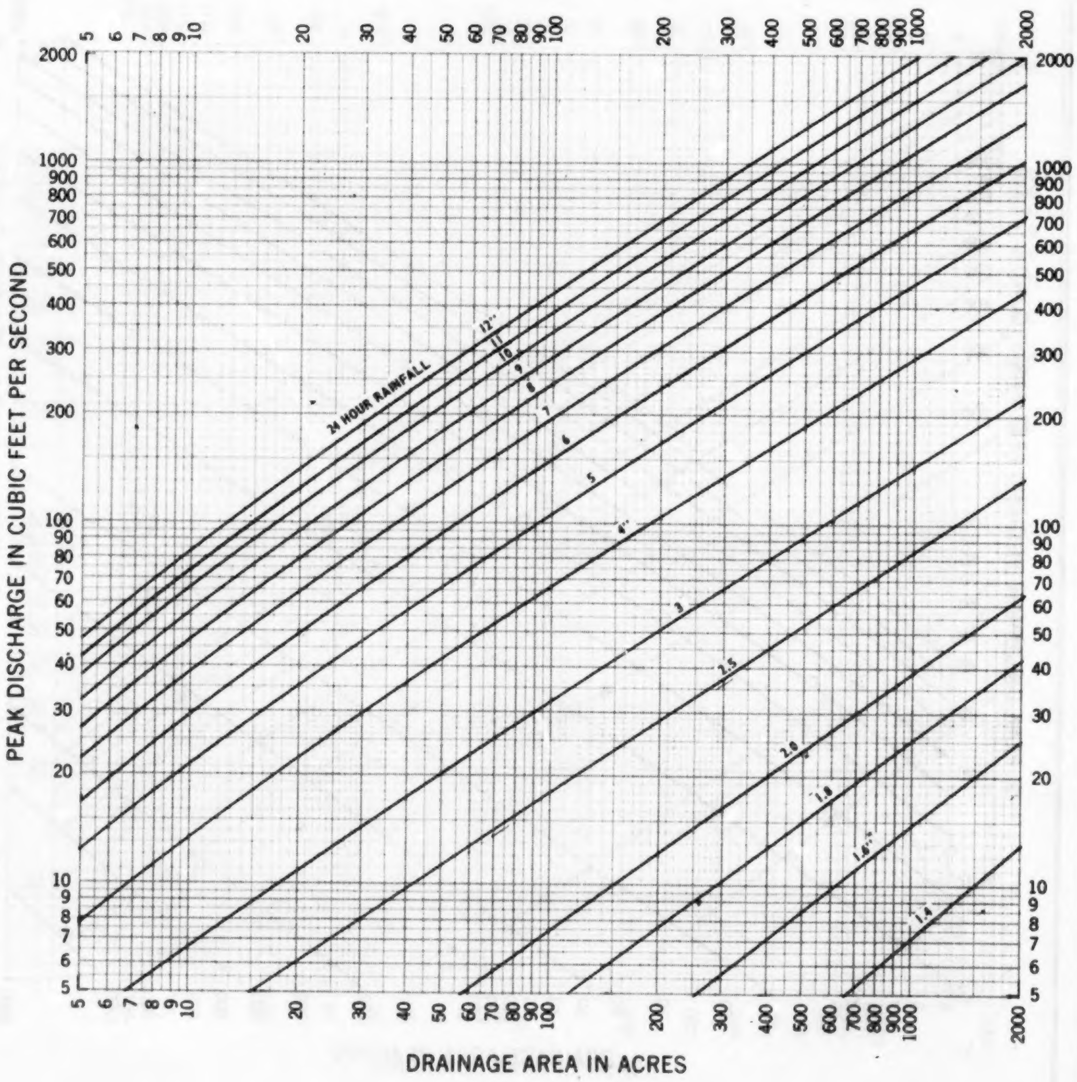

Exhibit 2-10

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 10 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 75

24 HOUR RAINFALL FROM US WB TP-40

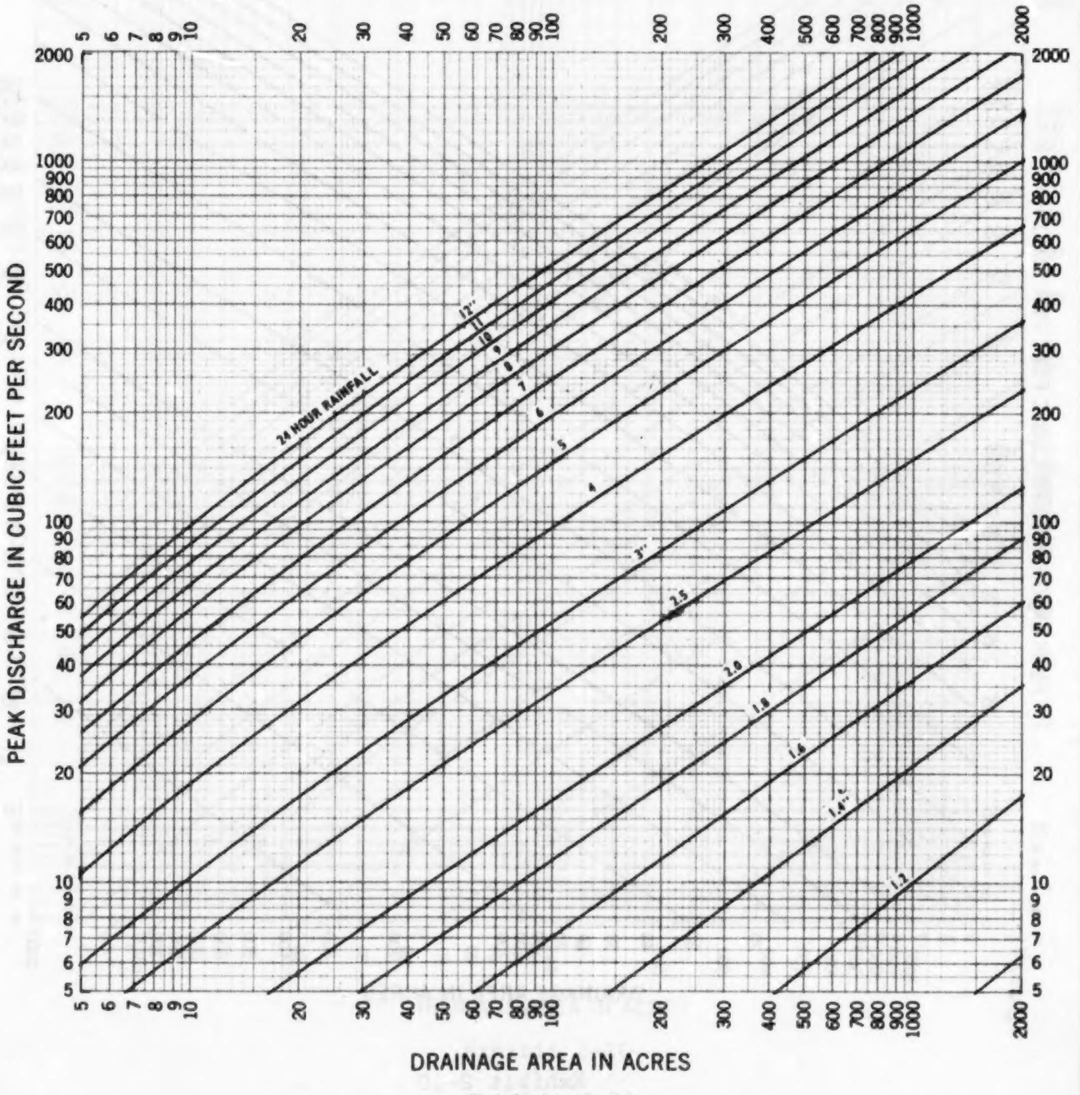

Exhibit 2-10

REFERENCE "Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	STANDARD DWG. NO. ES-1027 SHEET 11 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 80

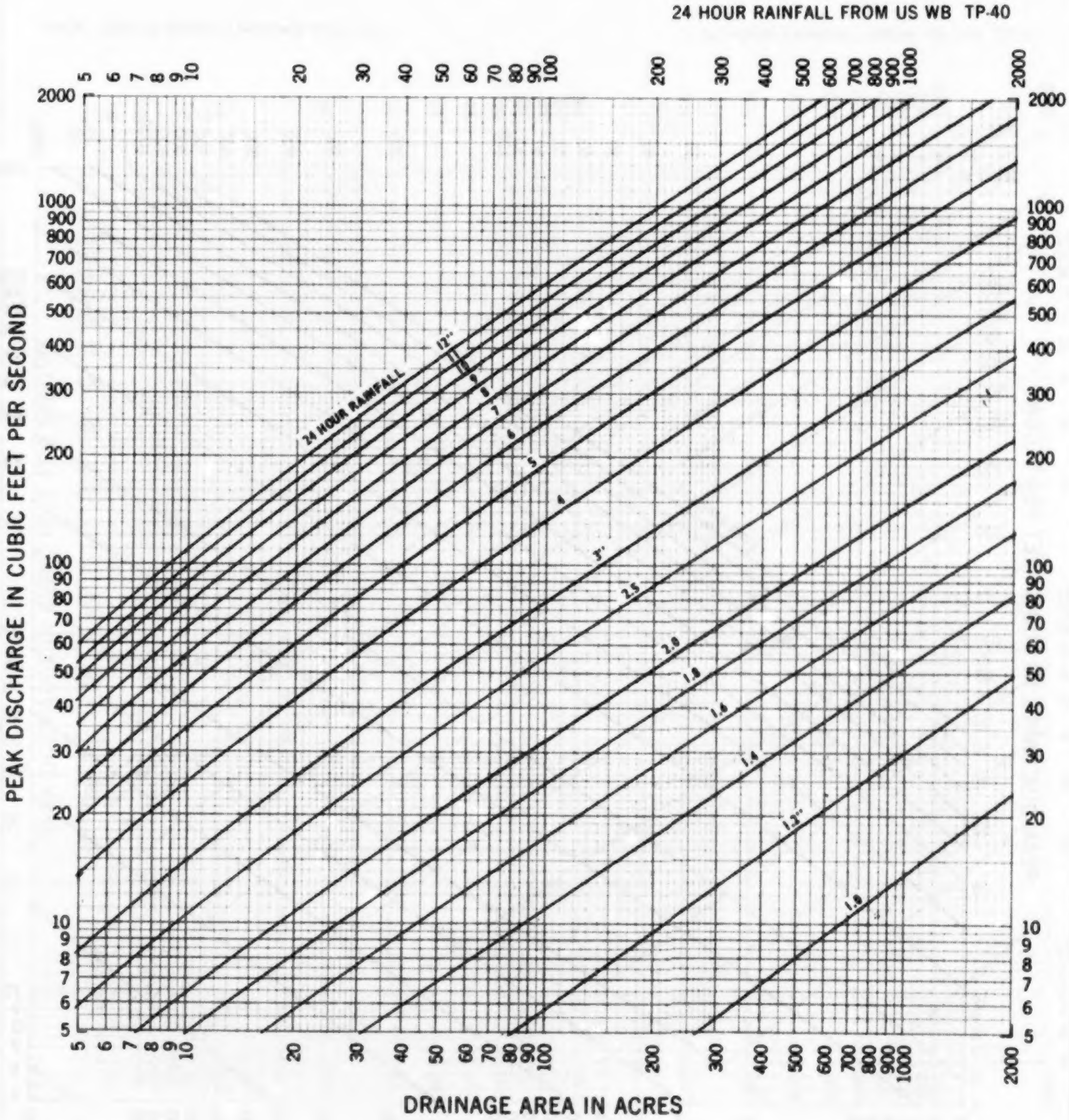

Exhibit 2-10

REFERENCE "Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	STANDARD DWG. NO. ES-1027 SHEET 12 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 85

24 HOUR RAINFALL FROM US WB TP-40

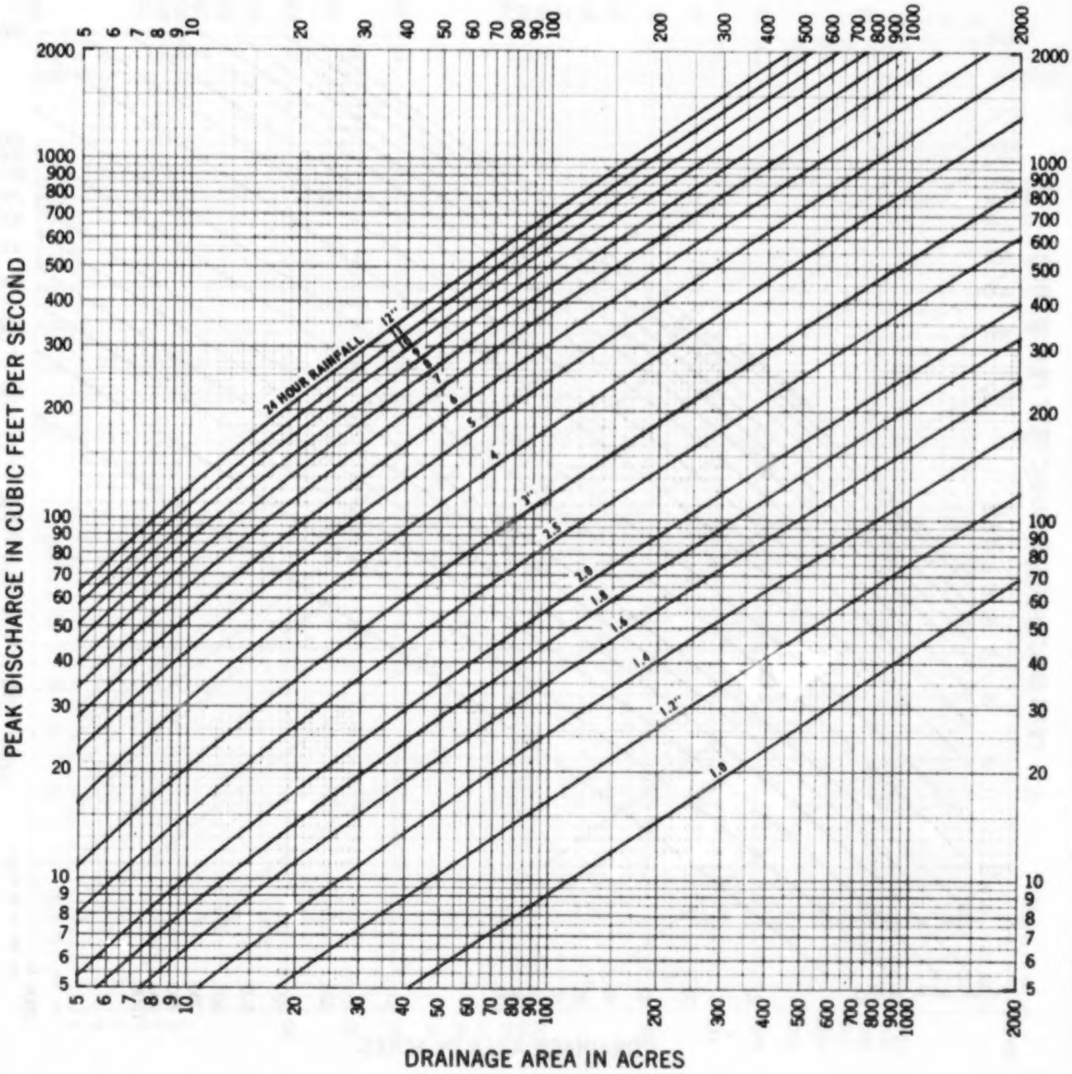

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual for Conservation Practices"

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STANDARD DWG. NO.
ES-1027
SHEET 13 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - MODERATE
CURVE NUMBER - 90

24 HOUR RAINFALL FROM US WB TP-40

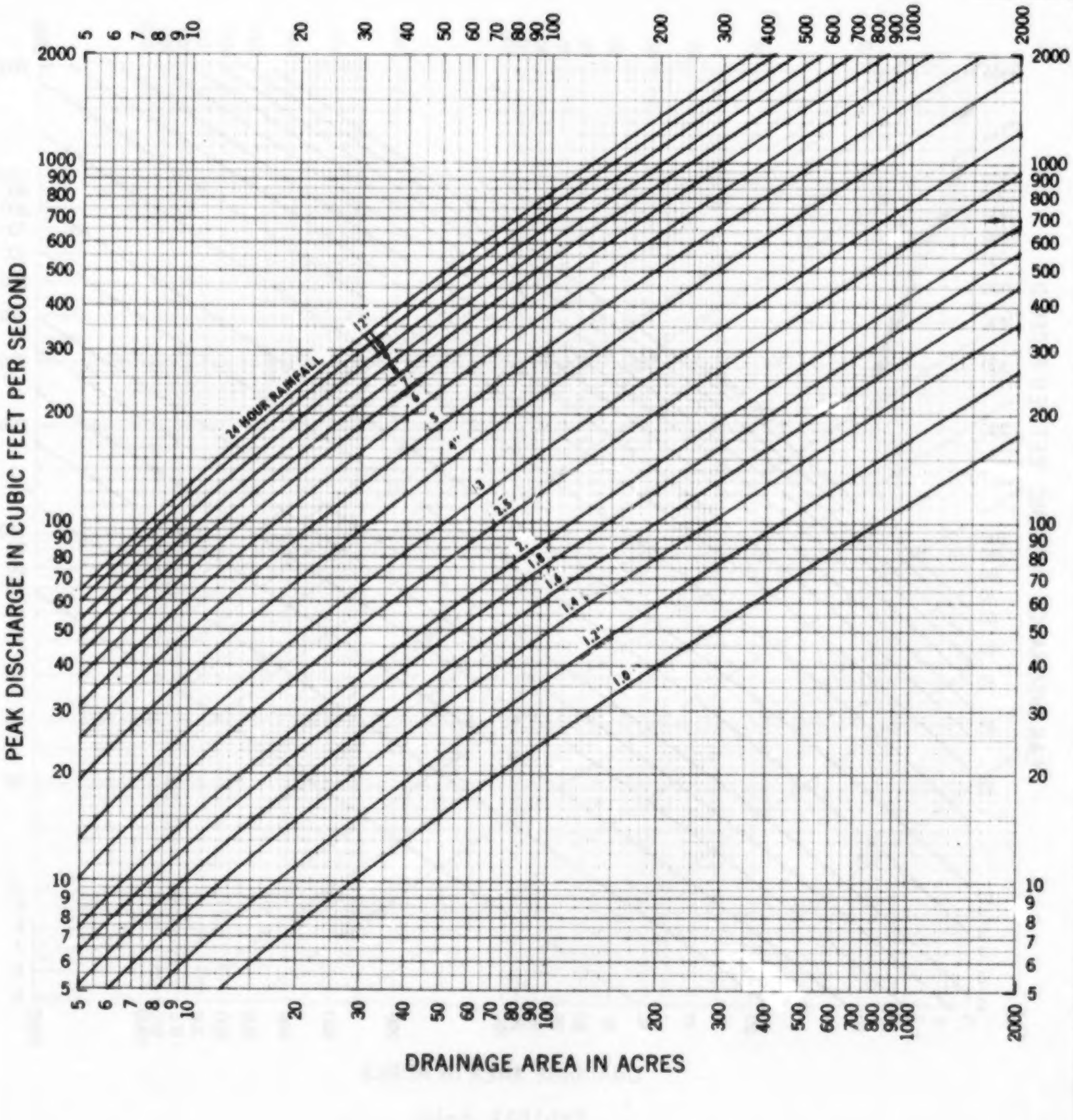

Exhibit 2-10

REFERENCE		STANDARD DWG. NO.
"Chapter 2, Engineering Field Manual for Conservation Practices"	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - HYDROLOGY BRANCH	ES-1027 SHEET 14 OF 21 DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - STEEP
CURVE NUMBER - 60

24 HOUR RAINFALL FROM US WB TP-40

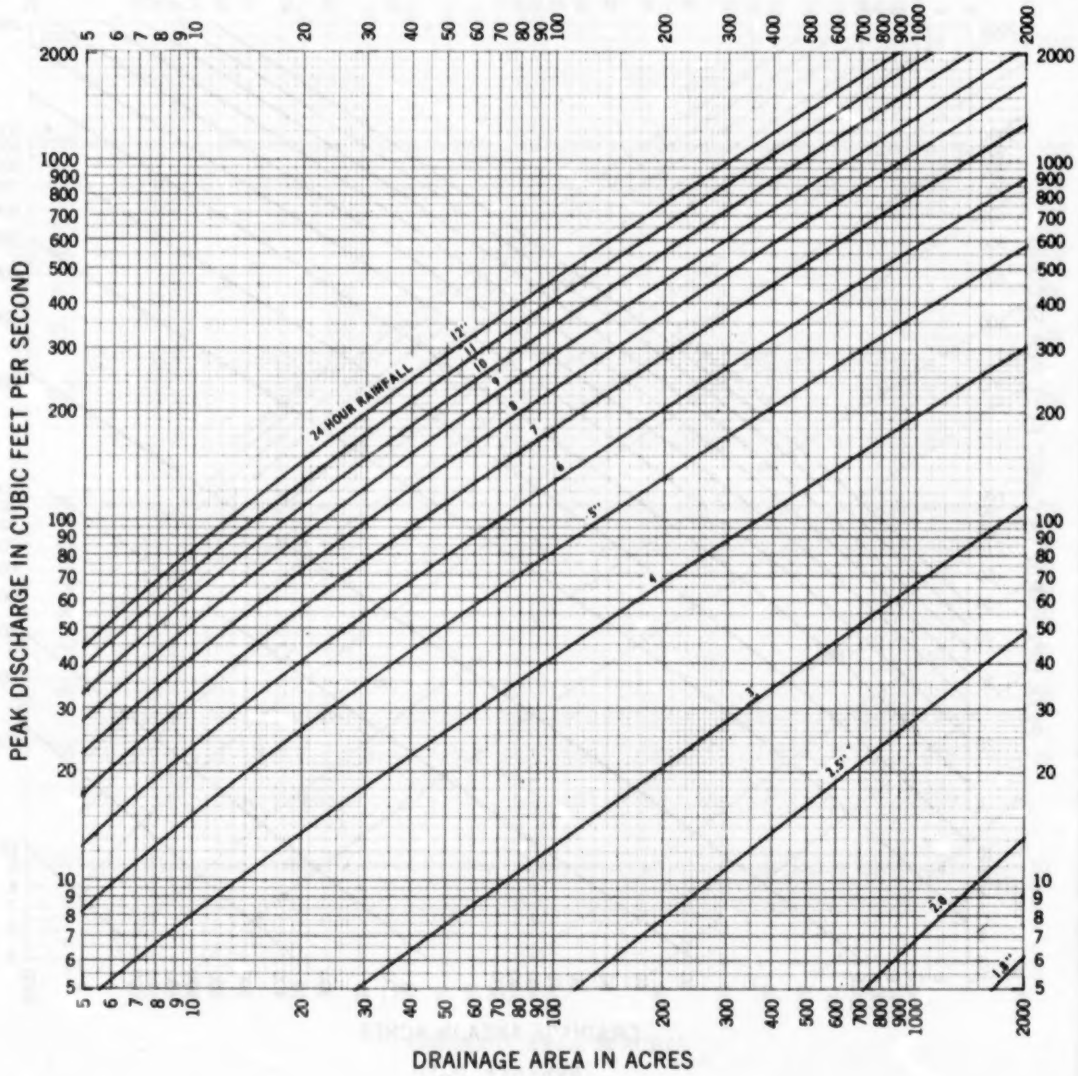

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual for Conservation Practices"

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STANDARD DWG. NO.
ES-1027
SHEET 15 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - STEEP
CURVE NUMBER - 65

24 HOUR RAINFALL FROM US WB TP-40

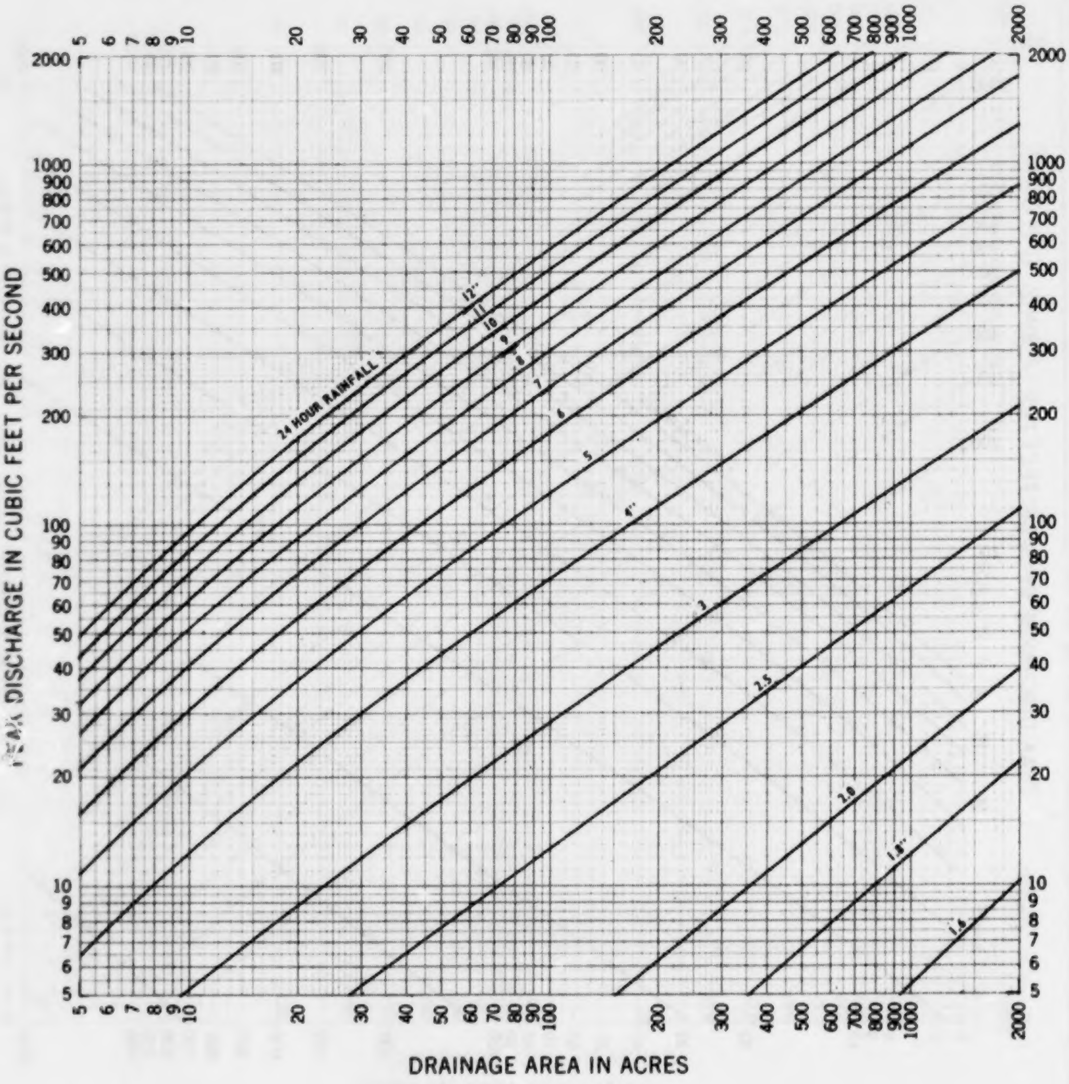

Exhibit 2-10

REFERENCE

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U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
SHEET 16 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - STEEP
CURVE NUMBER - 70

24 HOUR RAINFALL FROM US WB TP-40

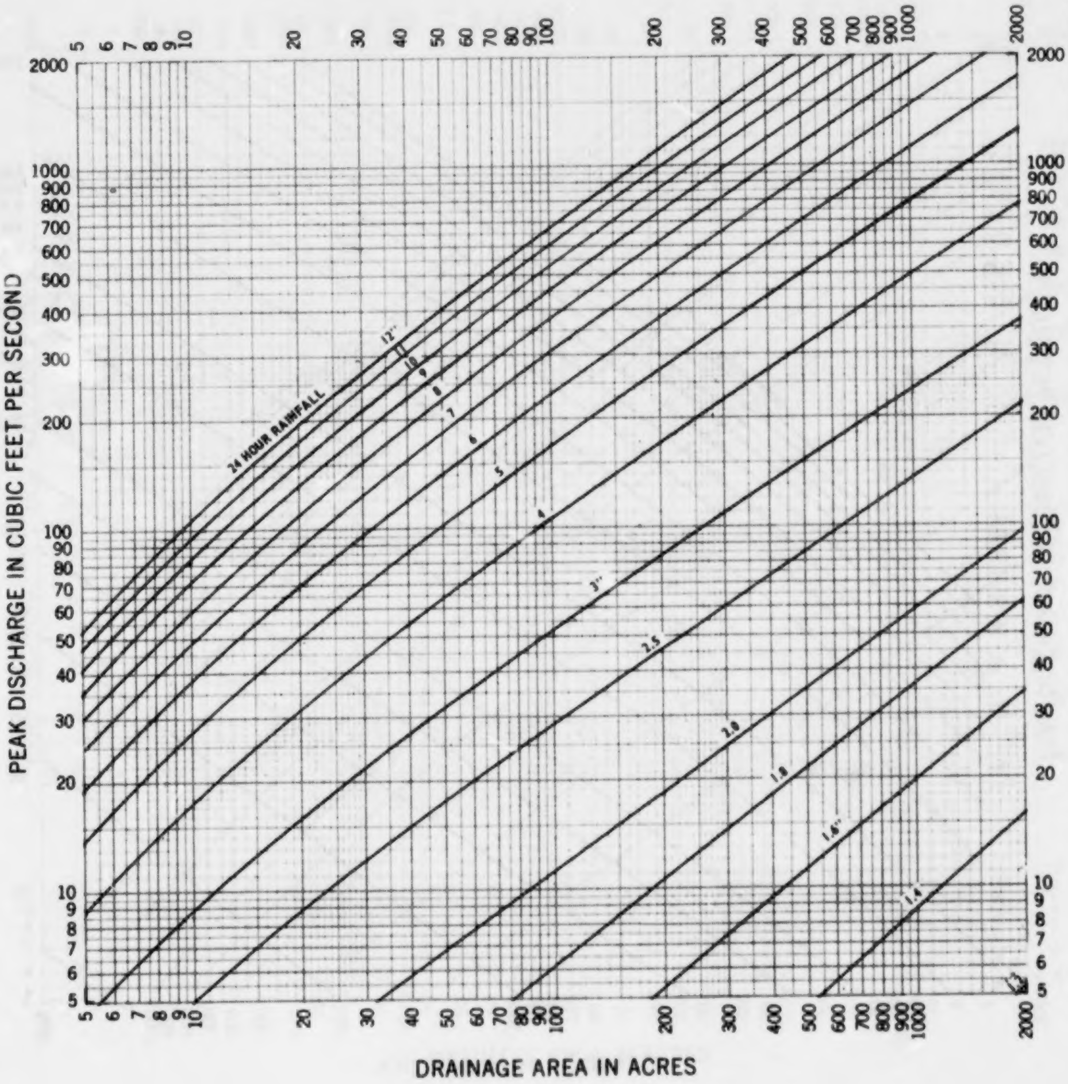

Exhibit 2-10

REFERENCE

"Chapter 2, Engineering Field Manual for Conservation Practices"

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ENGINEERING DIVISION - HYDROLOGY BRANCH

STANDARD DWG. NO.
ES-1027
SHEET 17 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - **STEEP**
CURVE NUMBER - 75

24 HOUR RAINFALL FROM US WB TP-40

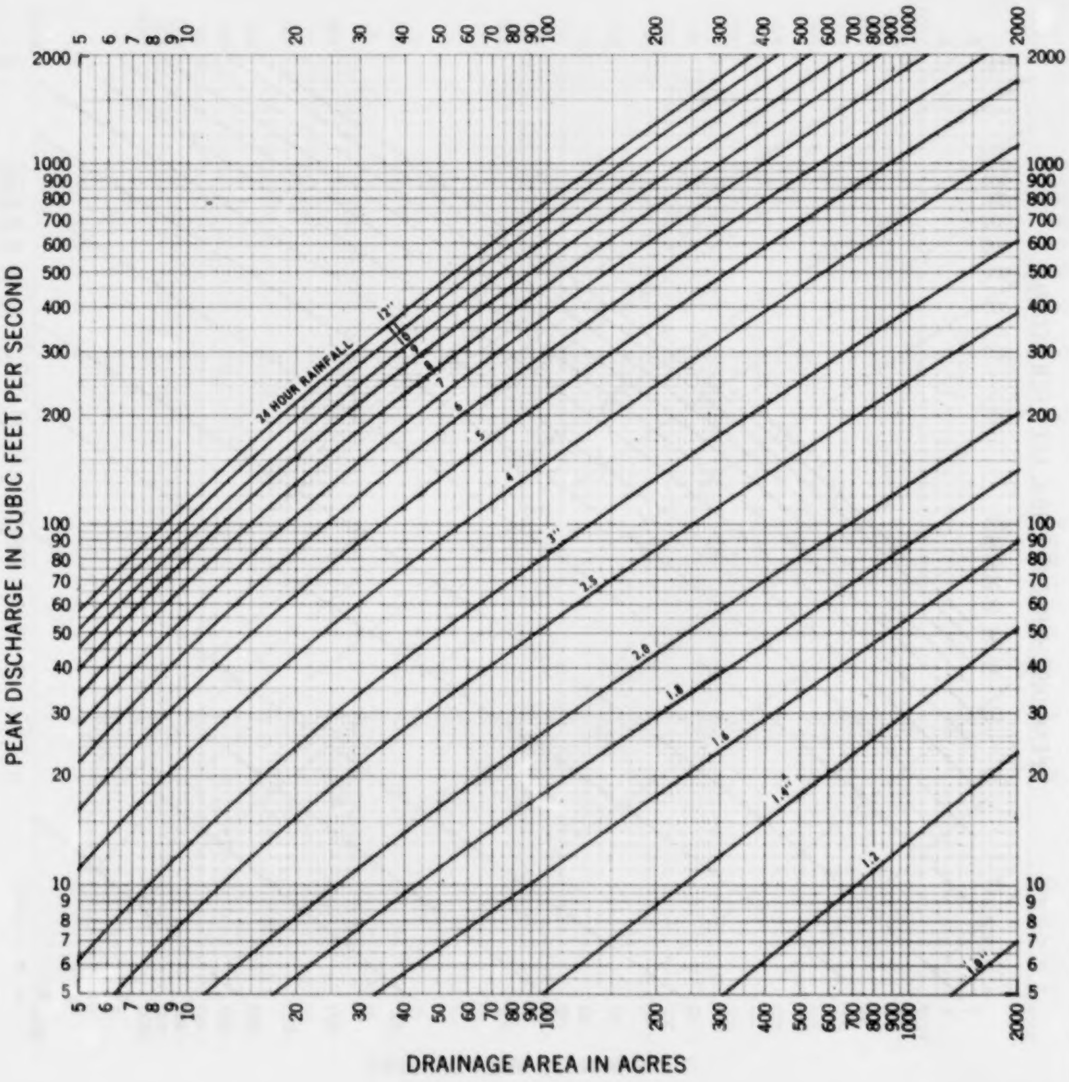

Exhibit 2-10

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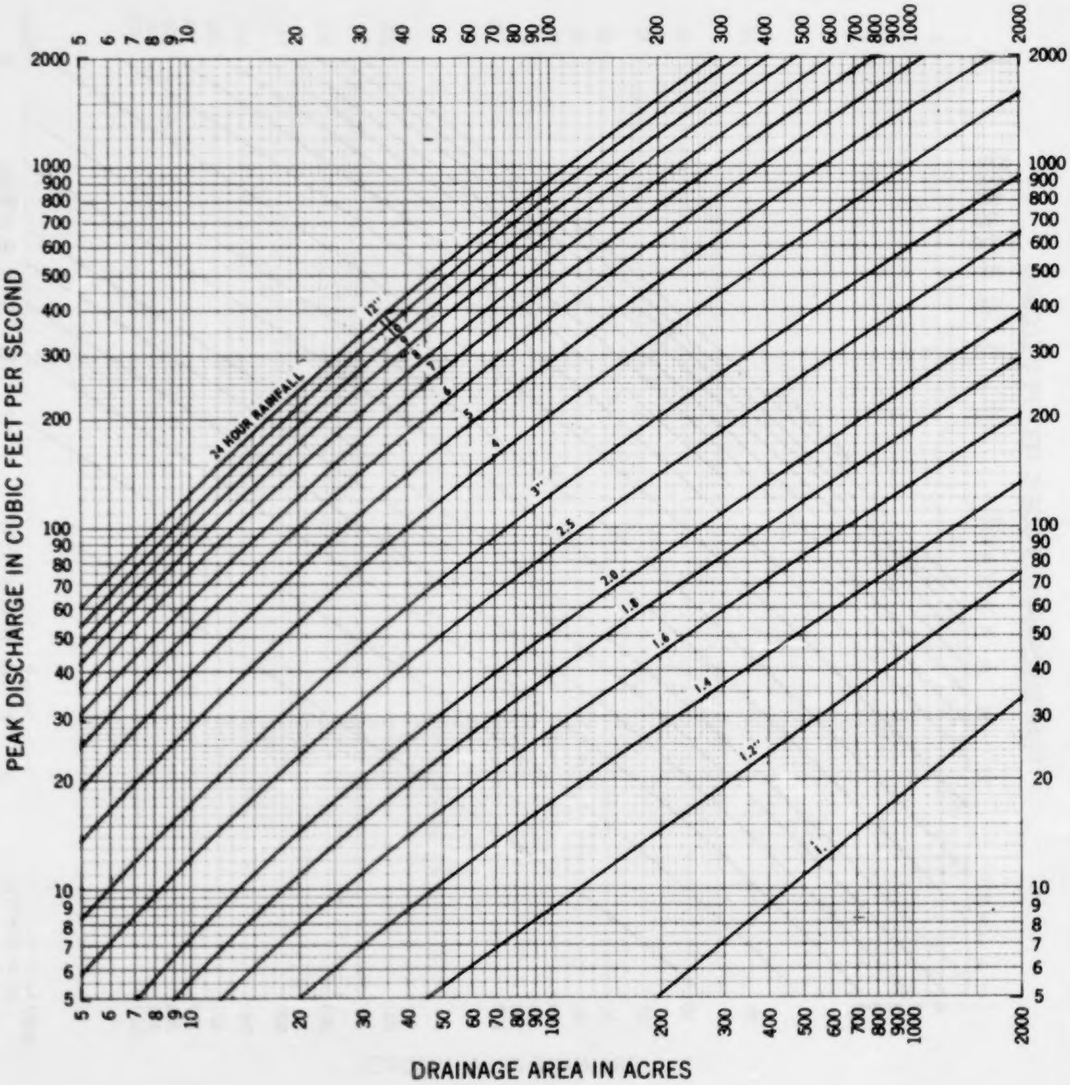
STANDARD DWG. NO.
ES-1027
SHEET 18 OF 21
DATE 2-15-71

PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - **STEEP**
CURVE NUMBER - 80

24 HOUR RAINFALL FROM US WB TP-40



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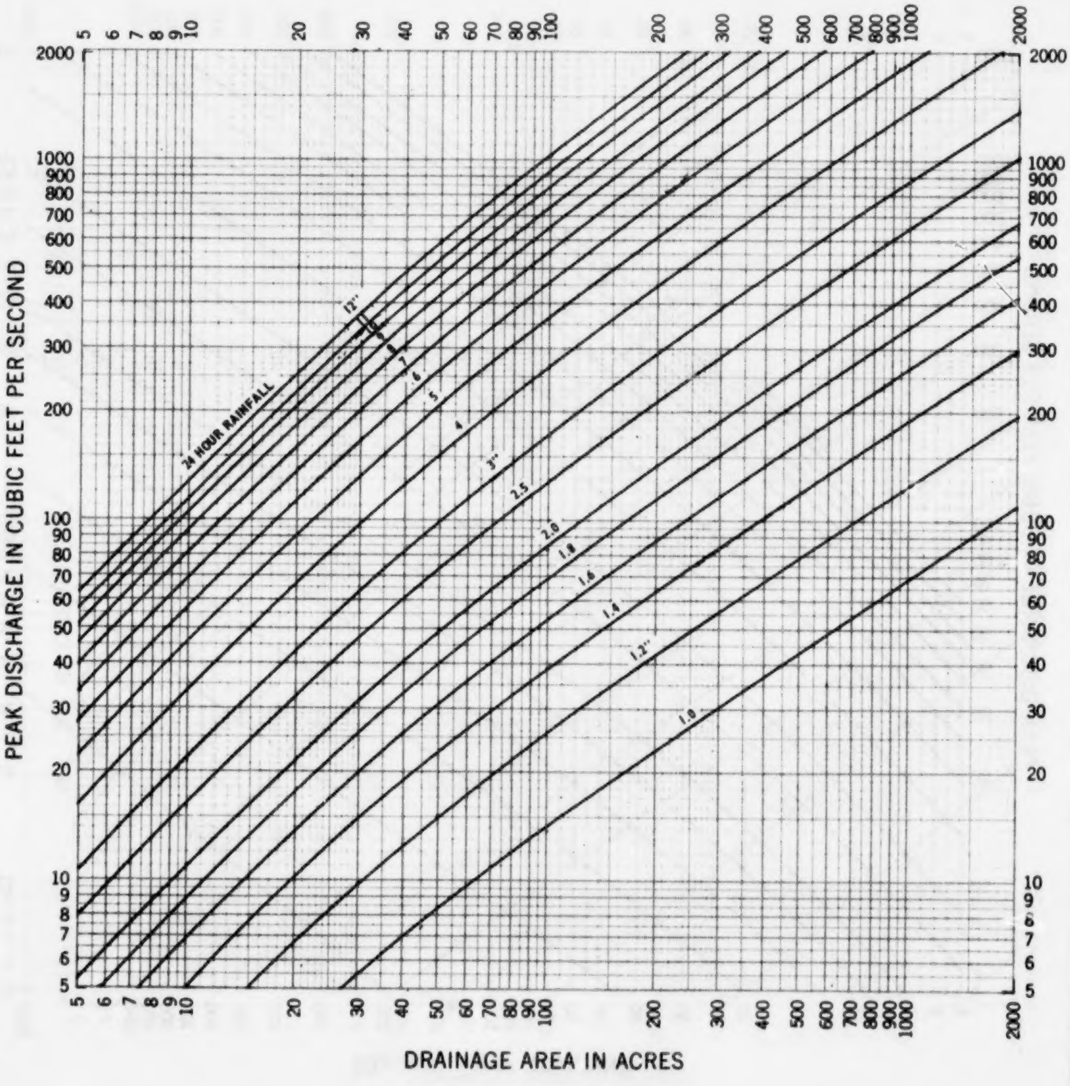
PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - STEEP
CURVE NUMBER - 85

24 HOUR RAINFALL FROM US WB TP-40



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PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS
TYPE II STORM DISTRIBUTION

SLOPES - STEEP
CURVE NUMBER - 90

24 HOUR RAINFALL FROM US WB TP-40

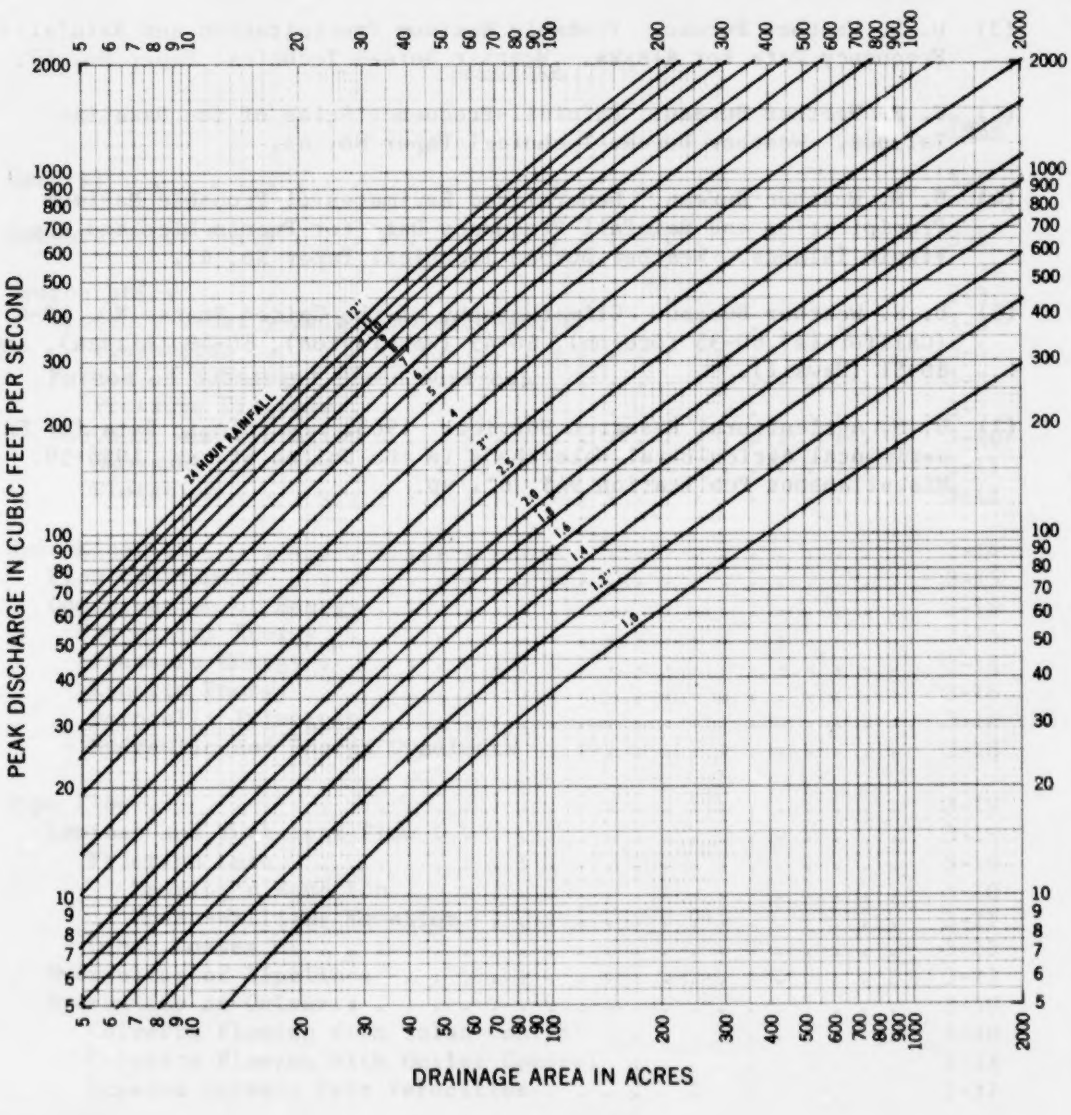

Exhibit 2-10

REFERENCE		STANDARD DWG. NO.
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(3) U. S. Weather Bureau. Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska. Weather Bureau Technical Paper No. 47.

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ENGINEERING FIELD MANUAL

CHAPTER 3. HYDRAULICS

Compiled by: William J. Urquhart, Civil Engineer, SCS, Portland, Oregon

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ENGINEERING FIELD MANUAL

CHAPTER 3. HYDRAULICS

1. GENERAL

This chapter presents the hydraulic principles that apply to the design and operation of soil and water conservation measures. It will help the technician to develop a better understanding of hydraulics and to use the equations and exhibits contained herein.

The chapter contains sections on conversion of units, principles of water at rest (hydrostatics), and principles of water in motion (hydrokinetics). It discusses the application of these principles to the flow of water in pipes, in open channels, and through weirs. Lastly, the more common methods of measuring the flow of water in open channels and pipes are covered.

2. CONVERSION OF UNITS

Valid equations must be expressed in corresponding units. That is, in a true equation there must be equality between both units and numbers. The chance of making conversion errors can be greatly reduced by forming the habit of thinking in terms of equality of units as well as their relative numerical values.

The foot-pound-second system is used in this chapter unless otherwise specified. Sometimes, however, it is necessary to convert to other units, which involves the use of numerical conversion constants. Some frequently used constants are given in Exhibit 3-1.

EXAMPLE 3-1

It is desired to build a stock water tank with a capacity in cubic feet that will contain one day's flow from a spring that flows at the rate of three gallons per minute.

3 gallons per minute per day = Y cubic feet

Since cubic feet can not be directly equated to gallons, some unit factor having numerical value must be introduced if the expression is to be made a valid equation.

The expression 3 gallons per minute per day is a fractional expression that can be written:

$$3\ \text{gal/min/day} = \frac{\dfrac{3\ \text{gal.}}{\text{min.}}}{\text{day}} = \frac{3\ \text{gal.}}{\text{min.}} \times \frac{\text{day}}{1} = \frac{3\ \text{gal.day}}{\text{min.}}$$

Analysis shows that:

$$\frac{3\ \cancel{\text{gal}}.\cancel{\text{day}}}{\cancel{\text{min}}.} \times \frac{60\ \cancel{\text{min}}.}{1\ \cancel{\text{hr}}.} \times \frac{24\ \cancel{\text{hr}}.}{1\ \cancel{\text{day}}} \times \frac{1\ \text{cu.ft.}}{7.48\ \cancel{\text{gal}}.} = 577.5\ \text{cu.ft.}$$

Note that all units on the left cancel except cubic feet, thus leaving the same units on each side of the equation. The result is the following general equation for conversions between gallons per minute per day and cubic feet. If 3 gal/min/day equals 577.5 cu.ft., one gal/min/day equals 192.51 cu.ft. Then:

$$X\ \text{gpm day} \times \frac{192.51\ \text{cu.ft.}}{1\ \text{gpm day}} = Y\ \text{cu.ft.}$$

EXAMPLE 3-2

1 acre foot per hour = Y gallons per minute

Step by step analysis results in a valid conversion equation consistent in both units and dimensions:

$$\frac{1\ \cancel{\text{ac}}.\cancel{\text{ft}}.}{\cancel{\text{hr}}.} \times \frac{43{,}560\ \cancel{\text{sq}}.\cancel{\text{ft}}.}{1\ \cancel{\text{ac}}.} \times \frac{1\ \cancel{\text{hr}}.}{60\ \text{min.}} \times \frac{7.48\ \text{gal.}}{1\ \cancel{\text{cu}}.\cancel{\text{ft}}.} = 5431\ \frac{\text{gal.}}{\text{min.}}$$

or

$$X\ \frac{\cancel{\text{ac}}.\cancel{\text{ft}}.}{\cancel{\text{hr}}.} \times \frac{\dfrac{5431\ \text{gal.}}{\text{min.}}}{\dfrac{\cancel{\text{ac}}.\cancel{\text{ft}}.}{\cancel{\text{hr}}.}} = Y\ \frac{\text{gal.}}{\text{min.}}$$

EXAMPLE 3-3

1 cubic foot per second day = Y acre feet

Analysis results in:

$$\frac{1\ \cancel{\text{cu}}.\text{ft}.\cancel{\text{day}}}{\cancel{\text{sec}}.} \times \frac{1\ \text{ac.}}{43{,}560\ \cancel{\text{sq}}.\cancel{\text{ft}}.} \times \frac{24\ \cancel{\text{hr}}.}{\cancel{\text{day}}} \times \frac{60\ \cancel{\text{min}}.}{\cancel{\text{hr}}.} \times \frac{60\ \cancel{\text{sec}}.}{\cancel{\text{min}}.} = 1.9835\ \text{ac.ft.}$$

$$X\ \cancel{\text{cfs}}\ \cancel{\text{day}} \times \frac{1.9835\ \text{ac.ft.}}{\cancel{\text{cfs}}\ \cancel{\text{day}}} = Y\ \text{ac.ft.}$$

If this approach to conversion problems is used, the results will be:

1. Freedom from conversion errors.
2. Savings in time in both original and "check" computations.
3. Accuracy of conversion factor selection from standard tables and other sources.

3. HYDROSTATICS

The subject of hydrostatics (fluid statics) deals with problems in which the fluid is motionless or at rest.

PRESSURE-DENSITY-HEIGHT RELATIONSHIPS

The fundamental equation of fluid statics relates pressure, density, and depth. Unit pressures in a fluid vary directly with the depth and the unit weight of the fluid and are expressed by the equation:

$$p = wh \quad \text{or} \quad h = \frac{p}{w} \qquad \text{(Eq. 3-1)}$$

where p = intensity of pressure per unit of area
w = unit weight of the fluid
h = depth of submergence, or head.

Equation 3-1 shows that pressure at any point in a liquid of given density depends solely upon the height of the liquid above the point. This allows the vertical height, or "head," of the liquid to be used as an indication of pressure. Thus, pressure may be quoted in such units as "inches of mercury" and "feet of water." The relationship of pressure and head is illustrated numerically in the "manometer" and "piezometer columns" of Figure 3-1.

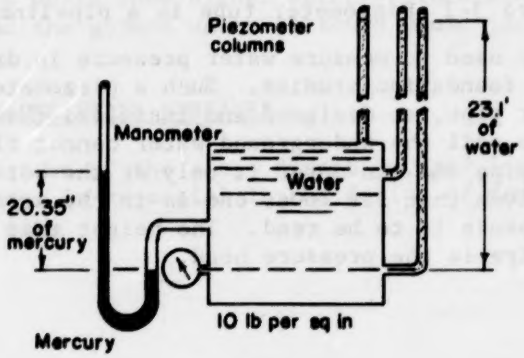


Figure 3-1 Relationship between pressure and head

If the tank is filled with water until the pressure gage reads 10 p.s.i., the height of the water surface in the piezometers and the mercury in the manometer can be calculated from Equation 3-1.

Example 3-4

Water:

$$h = \frac{p}{w} = \frac{\frac{10\text{ lb.}}{\text{sq.in.}}}{\frac{62.4\text{ lb.}}{\text{cu.ft.}}} \times \frac{144\text{ sq.in.}}{1\text{ sq.ft.}} = 23.1\text{ feet}$$

Mercury (unit weight of 849 pounds per cubic foot):

$$h = \frac{\frac{10\text{ lb.}}{\text{sq.in.}}}{\frac{849\text{ lb.}}{\text{cu.ft.}}} \times \frac{144\text{ sq.in.}}{1\text{ sq.ft.}} \times \frac{12\text{ in.}}{1\text{ ft.}} = 20.35\text{ inches}$$

Piezometer

Figure 3-2 shows a piezometer tube connected to a pipe in which the liquid is under pressure. The height h_1 is a measure of pressure at the wall of the pipe if the opening is at right angles to the wall and free of any roughness or projection into the moving liquid. The pressure at the wall of the pipe is: $p_1 = wh_1$ and that at the centerline $p = wh$.

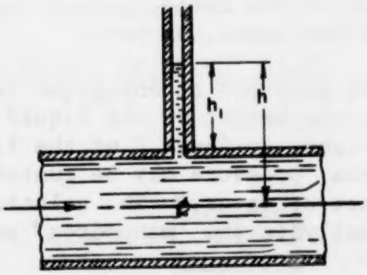


Figure 3-2 Piezometer tube in a pipeline

Piezometers are used to measure water pressure in drainage investigations and earth dam foundation studies. Such a piezometer is an unperforated small-diameter pipe, so designed and installed that after it has been driven into the soil the underground water cannot flow freely along the outside of the pipe and can enter it only at the bottom end. The piezometer is so driven that its lower end is in the stratum or at the level where the pressure is to be read. The height that water rises above the bottom of the pipe is the pressure head.

A piezometer should not be confused with an observation well which is used to determine the level of the water table. The well permits water to enter the hole at any level, thus connecting the various water bearing strata in the soil profile. The properly installed piezometer permits water to enter only at the bottom end and from only that level in the soil profile.

A typical example of the manner in which piezometers of different lengths may be used in sets to determine whether a canal is leaking is illustrated in Figure 3-3. In this example, sets of four piezometers 5, 10, 15 and 20 feet in length have been installed on a line at right angles to the axis of the canal at distances of 15, 60, and 100 feet from the centerline of the canal (Diagram A). The first objective is to obtain hydrostatic pressures at a large number of points under the water table adjacent to the canal.

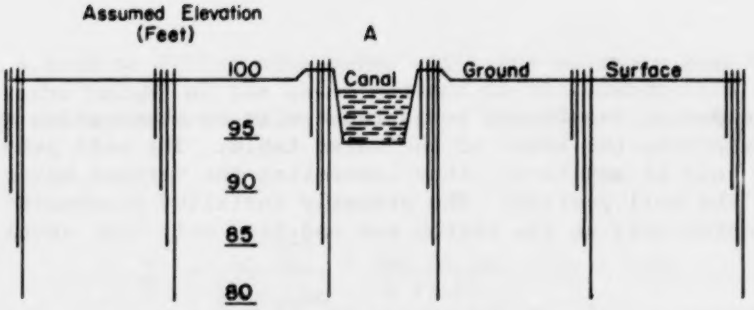
In Diagram B, which represents the same cross section shown in A, the small circles indicate the position of the bottom end of each piezometer. On the right-hand side of the sketch, the number beside each circle is the water level elevation in each piezometer. On the left side the numbers are the elevations of the bottom ends of the piezometers. Note that the water level elevations are greater than the elevations of the bottoms of the corresponding piezometers. The water surface elevation in the piezometer is written at the point in the profile where the bottom of the piezometer is located, not where the water surface is located.

The third step is to draw contours of equal hydrostatic pressures, as in Diagram C. These pressure lines are drawn in the vertical plane in much the same manner as ground surface contours are drawn in the horizontal plane. Water moves through the soil from high to low pressures and in a direction at right angles to the pressure contours. This example indicates seepage from the canal.

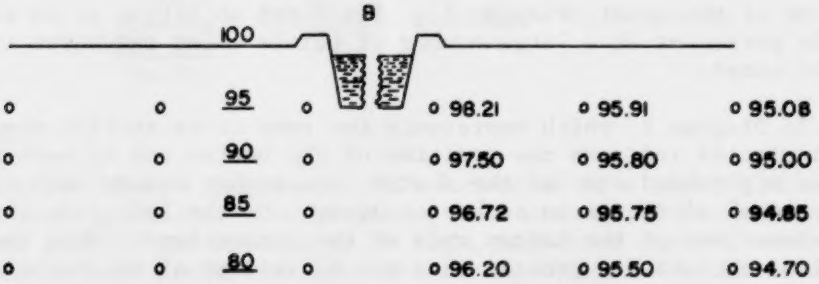
If an artesian pressure condition existed in the soil profile, the deep piezometers would show higher water surface elevations than the shorter piezometers, and the ground water contours would indicate upward water pressure.

FORCES ON SUBMERGED PLANE SURFACES

The calculation of the size, direction, and location of the forces on submerged surfaces is essential in the design of dams, bulkheads, water control gates, etc.

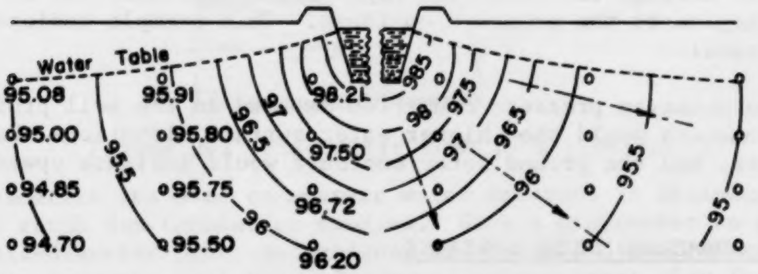

Assumed Elevation (Feet)
A
100
Canal
Ground
Surface
95
90
85
80

Six batteries of differential-length piezometers bracketing an irrigation canal and terminating at depths of 5, 10, 15, and 20 feet.


B
100
95
90
85
80
o 98.21
o 95.91
o 95.08
o 97.50
o 95.80
o 95.00
o 96.72
o 95.75
o 94.85
o 96.20
o 95.50
o 94.70

The left side is plotted to show the piezometer termination levels. The pressures in the piezometers are measured at these points.

The right side gives the water elevations in the piezometer tubes. These elevations are plotted at the piezometer termination points.


C
Water Table
95.08
95.91
98.21
95.00
95.80
97.50
94.85
95.75
96.72
94.70
95.50
96.20
98.5
98
97.5
97
96.5
96
95.5
95

The left side shows lines of equal pressure partly drawn. Lines of equal pressure are drawn similar to ground-surface contours.

The right side shows the finished lines of equal pressure and the arrows indicate the direction of ground-water movement.

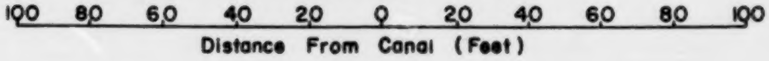

100 80 60 40 20 0 20 40 60 80 100
Distance From Canal (Feet)

Figure 3-3 Plotting differential-length piezometer data in the determination of equipotential pressure lines

For a submerged horizontal plane, the calculation of unit and total pressures is simple because the pressure is uniform over the area. For vertical and inclined planes the pressure varies with depth, as shown by Equation 3-1, producing the typical pressure diagrams and the resultant forces of Figure 3-4.

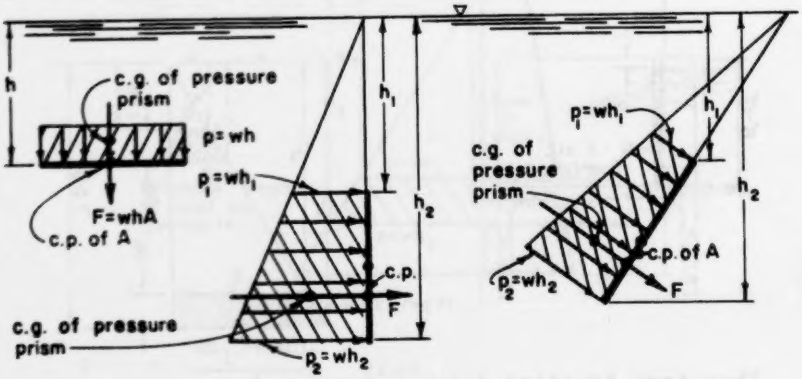


Figure 3-4 Pressure on submerged surfaces

The shaded area, when multiplied by a unit of length equals volume, which is known as the "pressure volume." The resultant force, F, is equal to the pressure volume and passes through its center of gravity (c.g.). The resultant force also passes through a point on the plane defined as the "center of pressure" (c.p.).

Pressure Diagrams

The analysis of structures under pressure usually will be simplified by use of pressure diagrams. Since unit pressure varies directly with head, diagrams showing the variation of unit pressure in any plane take the form of triangles, trapezoids, or rectangles.

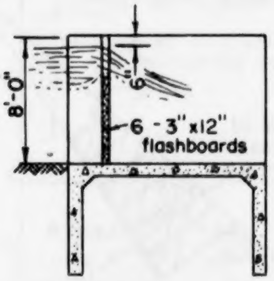
In solving problems of force due to water pressure, the magnitude, direction, and position of the force must be considered. The total force represented by the pressure diagram can, for some problems, be represented by a single force arrow through the pressure center acting in the same direction as the unit pressures.

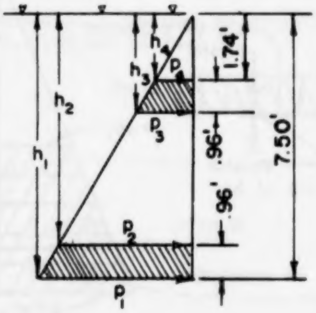
Exhibit 3-2 gives the most commonly used pressure diagrams and methods of computing the hydrostatic load and center of pressure.

Example 3-5

A flashboard type of dam is built with six 3 x 12-inch flashboards. What is (a) the load per foot on the bottom board, (b) the total load on the bottom board if it is six feet long, and (c) the load per foot on the top board?

Solution: First draw the pressure diagram, remembering that a finished 12-inch board is 11.5-inches or 0.96-foot wide.





Then from Equation 3-1:

$$p = wh = \text{unit weight of water} \times \text{depth of water}$$

$$p_1 = 62.4\,(7.5) = 468.0 \text{ lbs. per sq. ft.}$$
$$p_2 = 62.4\,(7.5 - 0.96) = 408.1 \text{ lbs. per sq. ft.}$$
$$p_3 = 62.4\,(1.74 + 0.96) = 168.5 \text{ lbs. per sq. ft.}$$
$$p_4 = 62.4\,(1.74) = 108.6 \text{ lbs. per sq. ft.}$$

And from Figure 3-4:

The hydrostatic load, $F = whA = pA = \text{unit pressure} \times \text{area}$

then

$$(a) = \frac{468.0 + 408.1}{2} \times 0.96 = 420.5 \text{ lbs. per ft.}$$

$$(b) = 420.5\,(6) = 2523 \text{ lbs.}$$

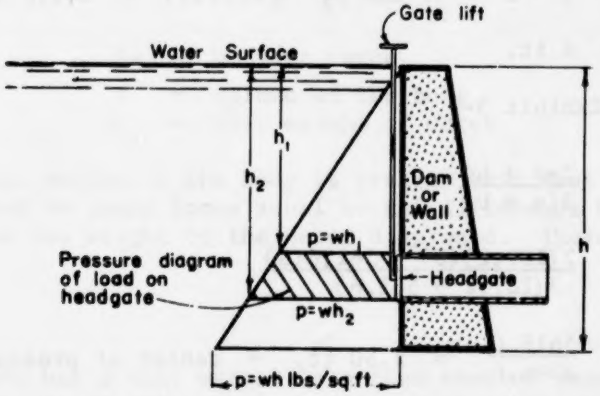
$$(c) = \frac{168.5 + 108.6}{2} \times 0.96 = 133.0 \text{ lbs. per ft.}$$

The solution would be the same for stoplogs in a water control structure.

Example 3-6

What is the total water load, F, on the headgate shown if it is 36-inches wide by 24-inches high, and h_1 is 9 feet?

Solution:


Gate lift
Water Surface
h_1
h_2
Dam or Wall
$p=wh_1$
Pressure diagram of load on headgate
Headgate
$p=wh_2$
h
$p=wh$ lbs/sq.ft

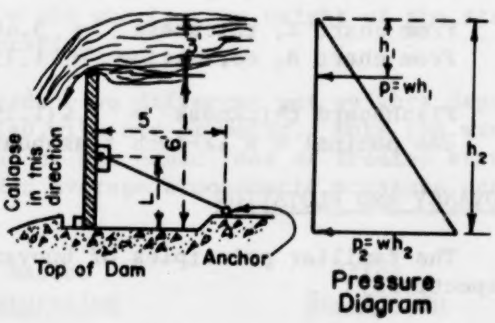
$$F = \frac{wh_1 + wh_2}{2} \quad \text{area}$$

$$h_2 = 9 + 2 = 11 \text{ feet}$$

$$F = 62.4\left(\frac{9 + 11}{2}\right)(2)(3) = 3744 \text{ lbs.}$$

Example 3-7

This sketch shows the cross section of a collapsible flashboard with water at the maximum allowable elevation. Determine the position of the center of pressure and the pivot under the conditions shown. Experience has shown that the pivot on the gate must be 6/7 of the distance from the bottom of the flashboard to the center of pressure for the board to collapse.


3'
5'
6'
Collapse in this direction
Top of Dam
Anchor
h_1
$p_1=wh_1$
h_2
$p_2=wh_2$
Pressure Diagram

Solution:

As defined, the center of pressure is the point where a perpendicular through the center of gravity of the pressure prism strikes the area under pressure. Use Exhibit 3-2 for the solution of this problem.

First draw the pressure diagram:

$h_1 = 3$ ft. and $p_1 = 62.4(3) = 187.2$ lbs/sq.ft. $= a$

$h_2 = 3 + 6 = 9$ and $p_2 = 62.4(9) = 561.6$ lbs/sq.ft. $= b$

$d = 6$ ft.

then from Exhibit 3-2

$$\bar{y} = \frac{2ad + bd}{3(a + b)}$$

$$= \frac{2(187.2)(6) + 561.6(6)}{3(187.2 + 561.6)}$$

$$= \frac{5616.0}{2246.6} = 2.50 \text{ ft.} = \text{center of pressure}$$

and

$$L = \frac{6}{7}(2.5) = 2.14 \text{ ft.}$$

Example 3-8

It is required to determine the maximum thickness of flashboards needed in a flashboard dam. The flashboards will impound water to a depth of 7 feet, have a 6-foot span, and be of Coast Region Douglas Fir.

This can be solved by the use of Exhibit 3-3.

From chart A, thickness = 3.40 inches
From chart B, correction = 1.15

Flashboard thickness = 3.4(1.15) = 3.91 inches
Use nominal 4 x 12-inch flashboards

BUOYANCY AND FLOTATION

The familiar principles of buoyancy and flotation are usually stated, respectively:

1. A body submerged in a fluid is buoyed up by a force equal to the weight of fluid displaced by the body.

2. A floating body displaces its own weight of the fluid in which it floats.

Buoyancy

A submerged body is acted on by a vertical, buoyant force equal to the weight of the displaced water.

$$F_B = Vw \qquad \text{(Eq. 3-2)}$$

F_B = buoyant force
V = volume of the body
w = unit weight of water

If the unit weight of the body is greater than that of water, there is an unbalanced downward force equal to the difference between the weight of the body and the weight of the water displaced. Therefore, the body will sink.

Flotation

If the body has a unit weight less than that of water, the body will float with part of its volume below and part above the water surface in a position so that:

$$W = Vw \qquad \text{(Eq. 3-3)}$$

W = weight of the body
V = volume of the body below the water surface; i.e., the volume of the displaced water
w = unit weight of water

A check should be made of the stability of hydraulic structures as they will be affected by submergence and whether the weight of the structure will be adequate to resist flotation.

Porous materials, when submerged, have different net weights depending upon whether the voids are filled with air or water. Note the wide variation in the possible net weight of one cubic foot of treated structural timber weighing 55 pounds under average atmospheric moisture conditions and having 30 percent voids:

1 cu. ft. of structural timber, 30 percent voids	Before Saturation	After Saturation
W = weight in air, lb.	55	$55 + (0.30 \times 62.4) = 73.72$
F_B = buoyant force when submerged, lb.	62.4	62.4
$W-F_B$ = weight when submerged in water (net weight), lb.	$55 - 62.4 = -7.4$	$73.72 - 62.4 = 11.32$

The degree to which the factors discussed above are capable of affecting the net or stabilizing weight of a structure is illustrated by the following example:

Example 3-9

Assume a timber crib diversion dam subject to complete submergence under normal flood flows. Materials, weights and volumes are:

Material	Percent of Volume of the Dam	Unit Weights lbs./cu. ft.
Timber	12	55 in air
Timber		73 saturated
Loose stone, 30 percent voids	88	150 solid stone

Determine the net weight of one cubic yard of the dam when 1) not submerged, 2) submerged but timber not saturated, and 3) submerged with timber saturated.

1. Compute cubic feet of timber, solid stone, and voids per cubic yard of dam:

   a. Timber $0.12 \times 27 = 3.24$ cu. ft.
   b. Solid stone $0.7 \times 0.88 \times 27 = 16.63$ cu. ft.
   c. Voids $0.3 \times 0.88 \times 27 = 7.13$ cu. ft.

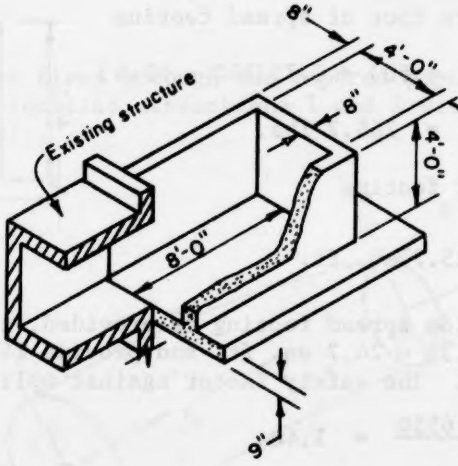
2. Compute the net weights of one cubic yard of dam:

Material	Net Weights of Materials in Pounds per Cubic Yard of Dam		
		Submerged	
	Not submerged	Timber not saturated	Timber saturated
Timber	3.24 x 55 = 178	3.24(55 - 62.4) = -24	3.24(73 - 62.4 = 34
Stone	16.63 x 150 = 2494	16.63(150 - 62.4) = 1457	1457
Effective or stabilizing weight of dam per cubic yard	2672	1433	1491

Example 3-10

A box inlet drop spillway for a 4 x 4-foot highway culvert is to be constructed. The box inlet has been designed as shown. Determine if it is safe from flotation with a safety factor of 1.5 and if not, determine the size of spread footing required. Design assumptions are as follows:

1. The soil is saturated to the lip of the box and has a buoyant weight of 50 pounds per cubic foot.
2. There is no frictional resistance between the walls of the box and the surrounding soil.
3. Unit weight of concrete - 150 pounds per cubic foot.
4. Unit weight of water - 62.4 pounds per cubic foot.



First determine the weight (W) of the box.

End wall = 4' x 4' x 0.67' x 150 = 1,608 lbs.

2 sidewalls = 4' x 8.67' x 0.67' x 150 x 2 = 6,907

Floor slab = 5.33 x 8.67 x 0.75 x 150 = 5,199

W = 13,714 lbs.

Next determine the buoyant force (F_B) acting on the box by Equation 3-2:

$$F_B = Vw = \left(5.33 \times 4.75 \times 8.67\right) 62.4 = 13{,}697 \text{ lbs.}$$

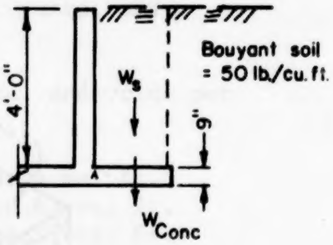
From Equation 3-3, flotation will occur if W is less than or equal to F_B (F_B has been substituted from Equation 3-2 for Vw):

13,714 lbs. is greater than 13,697 lbs., therefore, the box will not float, but the required safety factor of 1.5 has not been accomplished.

Required weight of box: $W = 1.5\ F_B = 1.5(13{,}697) = 20{,}546$ **lbs.**

Additional weight to be added to box = 20,546 - 13,714 = 6,832 lbs.

This additional weight will be provided with a spread footing around three sides of the box, and the weight of the earth load on the footing.



Weight per square foot of spread footing

$$= W_s + W_c = 4(50) + 0.75(150 - 62.4)$$

$$= 200 + 65.7 = 265.7 \text{ lbs.}$$

Required area of footing

$$= \frac{6832}{265.7} = 25.7 \text{ sq. ft.}$$

If a one foot wide spread footing is provided, the footing area would be 2(8.67) + 7.33 = 24.7 sq. ft. and provide 24.7(265.7) = 6550 lbs. of additional weight. The safety factor against uplift would be:

$$SF = \frac{13{,}714 + 6550}{13{,}697} = 1.48$$

Similarly, a spread footing 1'-3" wide would produce a safety factor of 1.57. By interpolation, a footing 1'-1" wide would meet the factor of safety requirement.

4. HYDROKINETICS

Hydrokinetics is the solution of fluid problems in which a change of motion occurs as the result of the application of a force to the fluid body (water in motion).

FLOW CONTINUITY

When the discharge through a given cross section of a channel or pipe is constant, the flow is steady. If steady flow occurs at all sections in a reach, the flow is continuous. This is known as continuity of flow and is expressed by the equation:

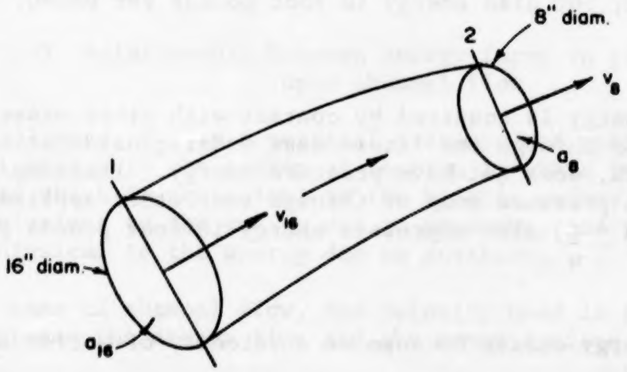
$$Q = a_1v_1 = a_2v_2 = a_3v_3 = a_nv_n \qquad \text{(Eq. 3-4)}$$

where Q = discharge in cubic feet per second
a = cross-sectional area in square feet
v = mean velocity of flow in feet per second
1, 2, 3, n = subscripts denoting different cross sections

Most of the hydraulic problems handled by field technicians deal with cases of continuous flow.

Example 3-11

10 cfs of water flows through the tapered pipe shown below. Calculate the average velocities at sections 1 and 2 with diameters of 16 and 8 inches respectively.



from Equation 3-4

$$Q = a_{16}V_{16} = a_8v_8$$

$$V_{16} = \frac{Q}{a16} \quad \frac{Q}{\frac{\pi}{4}d^2} \text{ where d, in feet, equals } \frac{16}{12}$$

$$= \frac{10}{\frac{\pi}{4}\left(\frac{16}{12}\right)^2} = \frac{10}{\frac{3.1416}{4}(1.333)^2} = 7.16 \text{ fps}$$

Similarly:

$$V_8 = \frac{Q}{a_8} = \frac{10}{\frac{\pi}{4}\left(\frac{8}{12}\right)^2} = 28.64 \text{ fps}$$

or, based on the ratio of cross-sectional areas

$$V_8 = V_{16}\left(\frac{a_{16}}{a_8}\right)^2 = 7.16\left(\frac{16}{8}\right)^2 = 28.64 \text{ fps}$$

CONSERVATION OF ENERGY

Three forms of energy are normally considered in the analysis of problems in water flow: Potential or elevation energy, pressure energy, and kinetic energy.

Potential Energy

Potential energy is the ability to do work because of the elevation of a mass of water with respect to some datum. A mass of weight, w, at an elevation z feet, has potential energy amounting to wz foot pounds with respect to the datum. The elevation head, z, expresses not only a linear quantity in feet, but also energy in foot pounds per pound.

Pressure Energy

Pressure energy is acquired by contact with other masses and is transmitted to or through the liquid mass under consideration. A mass of water, as such, does not have pressure energy. Pressure energy may be supplied by a pressure pump or through some other applied force. The pressure head ($h = \frac{p}{w}$) also expresses energy in foot pounds per pound.

Kinetic Energy

Kinetic energy exists because of a velocity of motion and amounts to:

$$\frac{Wv^2}{2g}$$

where W = weight of the water
v = velocity in feet per second
g = acceleration due to gravity

When W equals one pound, the kinetic energy has a value of $\frac{v^2}{2g}$.

This expression is called the velocity head. In other words, if the velocity of a stream of water is known, it is possible to compute the head which is converted from pressure energy or potential energy to create kinetic energy. This principle is extremely important in hydraulics.

Under certain conditions, the three forms of energy are interchangeable. The relationship between the three forms of energy in pipe and channel flow is shown by Figure 3-5.

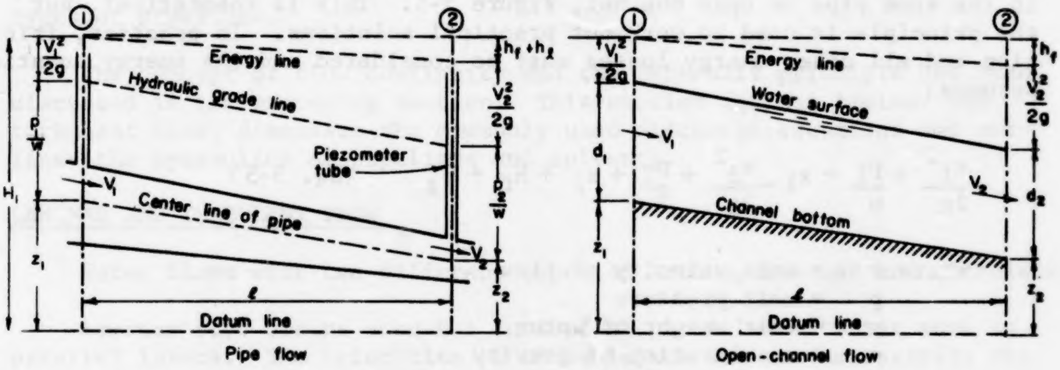

①
②
$\frac{V_1^2}{2g}$
Energy line
$h_f + h_\ell$
Hydraulic grade line
$\frac{V_2^2}{2g}$
$\frac{p}{w}$
Piezometer tube
H_1
V_1
Center line of pipe
$\frac{p_2}{w}$
V_2
z_1
z_2
ℓ
Datum line
Pipe flow
①
②
$\frac{V_1^2}{2g}$
Energy line
h_f
Water surface
$\frac{V_2^2}{2g}$
V_1
d_1
V_2
d_2
Channel bottom
z_1
z_2
ℓ
Datum line
Open-channel flow

Figure 3-5 Relationship between energy forms in pipe and open channel flow

The total head, H_1, is a vertical distance and represents the value of the total energy in the system at Section 1. This is made up of the velocity head which is equivalent to the kinetic energy, the pressure head which is equivalent to the energy due to pressure, and the elevation head which is equivalent to the energy due to position.

In the case of channel flow, the velocity head is the difference in elevation between the energy line and the water surface.

In the case of pipe flow, the velocity head is the difference between the elevation of the energy line and the elevation to which water would rise in a piezometer tube. In pipe flow the pipe may be lowered or raised within the zone of the elevation and the pressure heads without changing the conditions of flow. If the entrance end of the pipe is lowered, the elevation head is reduced, but the pressure head is increased a corresponding amount. Conversely, if the entrance end of the pipe is raised, the elevation head is increased and the pressure head is decreased. If the quantity of flow and diameter of pipe did not change, then the velocity head will remain the same.

Bernoulli Principle

Bernoulli's principle is the application of the law of conservation of energy to fluid flow. It may be stated as follows: In frictionless flow, the sum of the kinetic energy, pressure energy, and elevation energy is equal at all sections along the stream. This means that if we measured the velocity head, the pressure head, and the elevation head at one station in a pipe or open channel carrying flowing water without friction, we would find that the total would be equal to the total of the velocity head, the pressure head, and the elevation head at a second station downstream in the same pipe or open channel, Figure 3-5. This is theoretical, but the principle is used to work out practical solutions. In practice, friction and all other energy losses must be considered and the energy equation becomes:

$$\frac{v_1^2}{2g} + \frac{p_1}{w} + z_1 = \frac{v_2^2}{2g} + \frac{p_2}{2} + z_2 + h_f + h_\ell \qquad \text{(Eq. 3-5)}$$

where v = mean velocity of flow
p = unit pressure
w = unit weight of water
g = acceleration of gravity
z = elevation head
h_ℓ = all losses of head other than by friction between Stations 1 and 2 such as bends
h_f = head loss by friction between Stations 1 and 2
sub 1,2 denotes upstream and downstream stations, respectively

The energy equation and the equation of continuity ($Q = a_1 v_1 = a_2 v_2$) are the two basic, simultaneous equations used in solving problems in water flow.

Hydraulic and Energy Gradients

The hydraulic gradient in open-channel flow is the water surface, and in pipe flow it connects the elevations to which the water would rise in piezometer tubes along the pipe. The energy gradient is above the hydraulic gradient, a distance equal to the velocity head. In both open-channel and pipe flow, the fall (or slope) of the energy gradient for a given length of channel or pipe represents the loss of energy by friction. When considered together, the hydraulic gradient and the energy gradient reflect not only the loss of energy by friction, but also the conversions between the three forms of energy. See Figure 3-5.

5. PIPE FLOW

Pipe flow exists when a closed conduit of any form is flowing full. In pipe flow, the cross-sectional area of flow is fixed by the cross section of the conduit and the water surface is not exposed to the atmosphere. The internal pressure within a pipe may be equal to, greater than, or less than the local atmospheric pressure.

The principles of pipe flow apply to the hydraulics of such structures as culverts, drop inlets, regular and inverted siphons and various types of pipelines.

The concept of flow continuity and the Bernoulli principle has been discussed in the preceding section. This section defines laminar and turbulent flow, discusses the commonly used discharge equations and outlines the hydraulics of pipelines and culverts.

LAMINAR AND TURBULENT FLOW

Water flows with two different types of motion, laminar and turbulent.

Laminar flow occurs when the individual particles of water move in parallel layers. The velocities of these layers are not necessarily the same. However, the mean velocity of flow varies directly with the slope of the hydraulic gradient.

Turbulent flow is an irregular type of flow in which the particles follow unpredictable paths. In addition to the main velocity in the direction of flow, there are transverse components of velocity. The mean velocity of flow varies with the square root of the slope of the hydraulic gradient.

Laminar flow seldom occurs in pipe flow. It is the type of flow that water has through soils. For pipe flow the motion is turbulent.

Friction Loss

The loss of energy or head resulting from turbulence created at the boundary between the sides of the conduit and the flowing water is called friction loss.

In a straight length of conduit, flowing full, with constant cross section and uniform roughness, the rate of loss of head by friction is constant and the energy gradient has a slope in the direction of flow equal to the friction head loss per foot of conduit.

Of the many equations that have been developed to express this loss of head, the following two are the most widely used:

Manning's Equation

The general form of Manning's equation is:

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} \qquad \text{(Eq. 3-6)}$$

with the following nomenclature:

a = cross-sectional area of flow in ft.^{2}
d = diameter of pipe in feet
d_i = diameter of pipe in inches
g = acceleration of gravity = 32.2 ft. per sec.^{2}
H_l = loss of head in feet due to friction in length, L
K_c = head loss coefficient for any conduit
K_p = head loss coefficient for circular pipe
L = length of conduit in feet
n = Manning's roughness coefficient
p = wetted perimeter in feet
r = hydraulic radius in feet = $\frac{a}{p} = \frac{d}{4}$ for round pipe
s = loss of head in feet per foot of conduit = slope of energy grade and hydraulic gradelines in straight conduits of uniform cross section = $(H_l + L)$
v = mean velocity of flow in ft. per sec.
Q = discharge or capacity in cu.ft. per sec.

Starting with Equation 3-6 solve for s, multiply numerator and denominator of right side of equation by 2g and substitute $(H_l + L)$ for s. The result is:

$$H_l = \frac{29.164\ n^2\ L\ v^2}{2g\ r^{4/3}}$$

the equation can be simplified by substituting

$$K_c = \frac{29.164\ n^2}{r^{4/3}} \qquad \text{(Eq. 3-7)}$$

then the equation takes the form

$$H_l = K_c\ L\ \frac{v^2}{2g} \qquad \text{(Eq. 3-8)}$$

Adaption of Equation 3-7 to circular pipes involves the substitution of (d ÷ 4) for r and the change from d to d_i.

$$K_p = \frac{5087\ n^2}{d_i^{\ 4/3}} \qquad \text{(Eq. 3-9)}$$

Tables for values of K_p and K_c for the usual ranges of variables are given in Exhibit 3-4.

King's Handbook$^{(1)}$ gives a number of convenient working forms of Manning's formula and references to tables that will facilitate their use. Four of these are:

$$H_1 = 2.87\ n^2\ \frac{Lv^2}{d^{\ 4/3}}$$

$$H_1 = 4.66\ n^2\ \frac{LQ^2}{d^{\ 16/3}}$$

$$d = \left(\frac{2.159\ Qn}{s^{\ 1/2}}\right)^{3/8}$$

$$d_i = \left(\frac{1630\ Qn}{s^{\ 1/2}}\right)^{3/8}$$

Exhibit 3-5, which is based on the last of these equations, may be used to determine d_i, s, or Q when two of these quantities and n are known. Values of Manning's n are given in Table 3-1.

Hazen-Williams Equation

As generally used, this equation is:

$$v = 1.318\ C\ r^{0.63}\ s^{0.54} \qquad \text{(Eq. 3-10)}$$

Notation is the same as given for Manning's equation with the addition of C, the coefficient of roughness in Hazen-Williams formula.

Since Q = av, Equation 3-10 may be converted to the following formula for discharge in any conduit:

$$Q = 1.318\ a\ C\ r^{0.63}\ s^{0.54}$$

Substitution of a and r in terms of inside diameter of pipe in inches in this equation gives the following general formula for discharge in circular pipes:

$$Q/C = 0.0006273\ d_i^{2.63}\ s^{0.54} \qquad \text{(Eq. 3-11)}$$

Graphical solutions of Equation 3-11 for standard pipe ranging from 1 to 12 inches in diameter and a wide range in slope may be made by using Exhibit 3-6. Exhibit 3-7 gives losses for semi-rigid plastic pipe.

Values for C for different types of pipe are given in Table 3-2.

Regardless of the designer's preference of equations, the results should be checked against the application of State design criteria.

Table 3-1 Values of Manning's, n

Description of pipe	Values of n		
	Min.	Design	Max.
Cast-iron, coated	0.010	0.012 - 0.014	0.014
Cast-iron, uncoated	0.011	0.013 - 0.015	0.015
Wrought iron, galvanized	0.013	0.015 - 0.017	0.017
Wrought iron, black	0.012		0.015
Steel, riveted and spiral	0.013	0.015 - 0.017	0.017
Annular corrugated metal	0.021	0.021 - 0.025	0.0255
Helical corrugated metal	0.013	0.015 - 0.020	0.021
Wood stave	0.010	0.012 - 0.013	0.014
Neat cement surface	0.010		0.013
Concrete	0.010	0.012 - 0.017	0.017
Vitrified sewer pipe	0.010	0.013 - 0.015	0.017
Clay, common drainage tile	0.011	0.012 - 0.014	0.017
Corrugated plastic	0.014	0.015 - 0.016	0.017

Table 3-2 Values of Hazen-Williams C

Description of pipe	C
Very smooth pipe; straight alignment	140
Very smooth pipe; slight curvature	130
Cast iron, uncoated - new	130
5 years old	120
10 years old	110
15 years old	100
20 years old	90
30 years old	80
coated - all ages	130
Steel pipe, welded, new	130
(Same deterioration with age as cast iron, uncoated)	
For permanent installation use	100
Wrought iron or standard galvanized steel - dia. 12-in. up	110
4 to 12 in.	100
4 in. down	80
Brass or lead, new	140
Concrete, very smooth, excellent joints	140
smooth, good joints	120
rough	110
Vitrified	110
Smooth wooden or wood stave	120
Asbestos cement	140
Corrugated pipe	60

Note: Pipes of small diameter, old age, and very rough inside surface, may give values as low as C = 40

Other Losses

In addition to the friction head losses, there are other losses of energy which occur as the result of turbulence created by changes in velocity and direction of flow. To facilitate their inclusion in Bernoulli's energy equation, such losses are commonly expressed in terms of the mean velocity head at some specific cross section of the pipe.

These losses are sometimes called minor losses, which may be a serious misnomer. In long pipelines, the entrance loss, bend losses, etc., may be only a small part of the total loss and in such cases can be ignored. Such is not the case in many structures such as culverts, drop inlets, and siphons which are relatively short. Safe design practice requires an estimate of such losses. If the estimate indicates that minor losses amount to 5 percent or more of the total head loss, they should be carefully evaluated and included in the flow calculations.

As velocities increase, careful determination of such minor losses becomes more important. With a mean velocity of 30 feet per second, the neglect of an entrance loss of 0.5 $v^2/2g$ results in an error in head loss of 7 feet. Whereas, if the mean velocity is 3 feet per second, neglect of such an entrance loss results in an error of only 0.07 foot.

Data on minor losses most commonly required are contained in Exhibit 3-8 of this chapter, and Section 5, Hydraulics,(6) and Section 15, Irrigation, of the National Engineering Handbook.

HYDRAULICS OF PIPELINES

The pipe flow condition often found in SCS work is that of free flow discharge. See Figure 3-6.

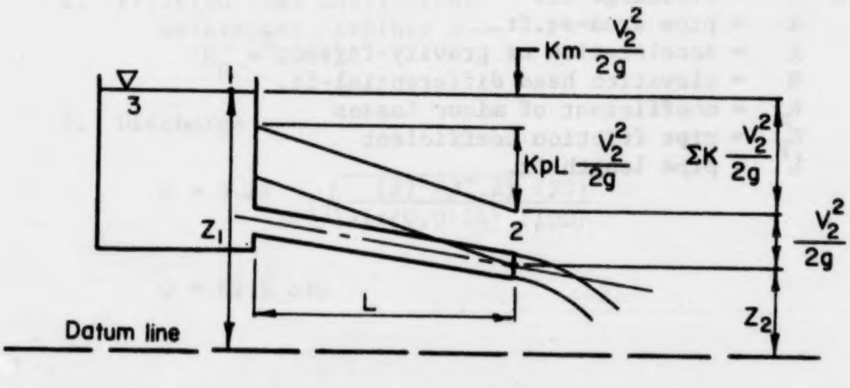


Figure 3-6 Pipe flow energy relationships

The general pipe flow equation is derived through use of the Bernoulli and continuity principles.

Equating the energy in Figure 3-6, using Equation 3-5:

$$0 + 0 + z_1 = \frac{v_2^2}{2g} + 0 + z_2 + \Sigma K \frac{v_2^2}{2g}$$

where z_1 = elevation head at station 1

z_2 = elevation head at station 2

v_2 = velocity head at station 2

$\Sigma K \frac{v_2^2}{2g}$ = sum of the minor head losses and pipe friction losses

Let $H = z_1 - z_2$

$$H = z_1 - z_2 = \frac{v_2^2}{2g}(1 + \Sigma K)$$

or

$$v_2 = \sqrt{\frac{2gH}{1+K_m+K_pL}}$$

and from the continuity principle

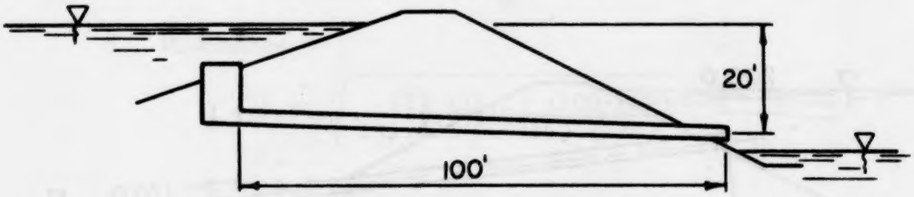
$$Q = a\sqrt{\frac{2gH}{1+K_m+K_pL}} \qquad \text{(Eq. 3-12)}$$

where Q = discharge-cfs
a = pipe area-sq.ft.
g = acceleration of gravity-ft/sec.^{2}
H = elevation head differential-ft.
K_m = coefficient of minor losses
K_p = pipe friction coefficient
L = pipe length-ft.

The following examples are applications of Equation 3-12.

Example 3-12

Determine the discharge of a drop inlet spillway with cantilevered outlet for a head H of 20 feet. The spillway is 24-inch diameter reinforced concrete pipe with Manning's n of 0.013, Table 3-1. K_m is 1.0 for bend and entrance losses. See reference, sheet 2 of Exhibit 3-8.



Solution

Using equation (3-12)

$$Q = a\sqrt{\frac{2gH}{1+K_m+K_pL}}$$

1. Area
   Reference: Exhibit 3-4
   $a = 3.14$ sq ft

2. Friction loss coefficient
   Reference: Exhibit 3-4
   $K_p = 0.0124$

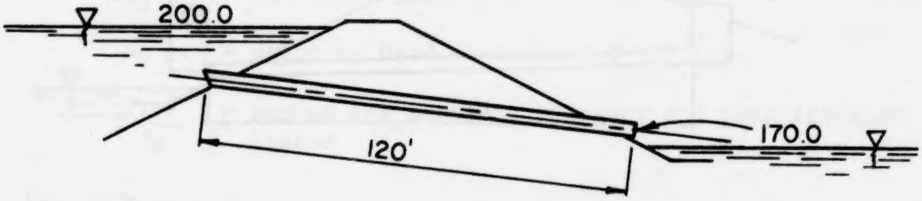
3. Discharge

$$Q = 3.14\sqrt{\frac{(2)\ (32.2)\ (20)}{1+1+(0.0124)\ (100)}}$$

$$Q = 62.5 \text{ cfs}$$

Example 3-13

A corrugated metal pipe with a hooded inlet and cantilevered outlet is to discharge 130 cfs when the reservoir water surface is at elevation 200.0 and the centerline of the outlet is at elevation 170.0. Determine the diameter of pipe required. Use Manning's n = 0.024, Table 3-1.



Solution

Select a diameter and determine the discharge using Equation 3-12.

$$Q = a\sqrt{\frac{2gH}{1+K_m+K_pL}}$$

Trial 1

1. Select d = 36 inches

2. Area
   Reference: Exhibit 3-4
   $a = 7.07$ sq.ft.

3. Friction loss coefficient
   Reference: Exhibit 3-4
   $K_p = 0.0246$

4. Minor loss coefficient
   Reference: Exhibit 3-8 ($K_m=K_e+K_b=K_e+0=K_e$)
   entrance $K_m = 1.00$

5. Discharge

$$Q = 7.07\sqrt{\frac{(2)\ (32.2)\ (200-170)}{1+1.00+(0.0246)\ \ (120)}}$$

$$Q = 138.0 \text{ cfs}$$

Trial 2

1. Select d = 30 inches
2. Area a = 4.91 sq.ft.
3. Friction loss coefficient $K_p = 0.0314$
4. Minor loss coefficient $K_m = 1.00$
5. Discharge

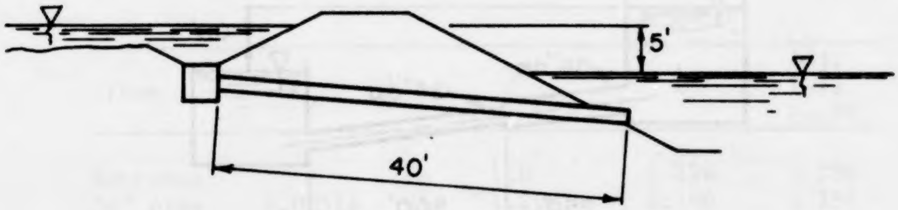
$$Q = 4.91 \sqrt{\frac{(2)\ (32.2)\ (200-170)}{1+1.00+(0.0314)\ (120)}}$$

$$Q = 90.0 \text{ cfs}$$

It can be seen from the foregoing two trials that the 36-inch pipe more nearly satisfies the required Q of 130 cfs and is the one to be installed.

Example 3-14

An 8-inch diameter concrete side drain inlet discharges below the water surface of a channel. The pipe is 40 feet long and flowing full with a head of 5 feet. Manning's n = 0.012, Table 3-1. Determine the discharge. Assume K_m = entrance coefficient plus bend coefficient = 1.



The discharge equation for exit conditions other than free flow is the same as Equation 3-12.

$$Q = a \sqrt{\frac{2gH}{K_x+K_m+K_pL}}$$

K_x = exit coefficient = 1.0

therefore

$$Q = a\sqrt{\frac{2gH}{1+K_m+K_pL}}$$

1. Area
   Reference: Exhibit 3-4
   $a = 0.349$ sq.ft.

2. Friction loss coefficient
   Reference: Exhibit 3-4
   $K_p = 0.0458$

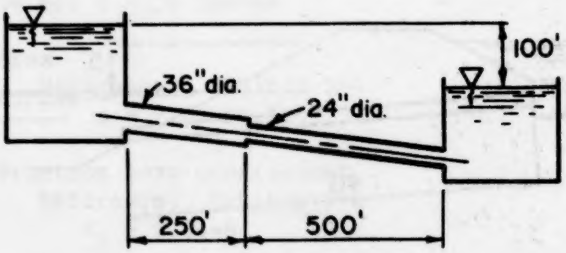
3. Discharge

$$Q = 0.349\sqrt{\frac{(2)\ (32.2)\ (5)}{1+1+(0.0458)\ (40)}}$$

$$Q = 3.2 \text{ cfs}$$

Example 3-15

A pipeline of 250 feet of 36-inch and 500 feet of 24-inch steel pipe connects two reservoirs. Determine the discharge if: the head is 100 feet, the entrance coefficient is 1, the contraction coefficient is 0.25, and Manning's n is 0.011.



To use Equation 3-12 the loss coefficients must be expressed in terms of a single-sized pipe.

In terms of the 24-inch pipe the coefficients in the example must be multiplied by the following ratio, C, which is based on the square of the ratio of areas.

$$C_{36} = \left(\frac{\text{area of 24" dia. pipe}}{\text{area of 36" dia. pipe}}\right)^2$$

$$C_{24} = \left(\frac{\text{area of 24" dia. pipe}}{\text{area of 24" dia.pipe}}\right)^2$$

Discharge in terms of 24-inch diameter pipe

1. **Areas**

   Reference: Exhibit 3-4

   24-inch dia. a = 3.14 sq.ft.

   36-inch dia. a = 7.07 sq.ft.

2. **Friction loss coefficients**

   Reference: Exhibit 3-4

   24-inch dia. $K_p = 0.00889$

   36-inch dia. $K_p = 0.00518$

3. **Square of the ratio of areas**

$$C_{24} = \left(\frac{3.14}{3.14}\right)^2 = 1.0$$

$$C_{36} = \left(\frac{3.14}{7.07}\right)^2 = 0.196$$

4. **Sum of the loss coefficients**

Item	K_p	L	K	C	Adj. loss coeff.
Entrance	-	-	1.0	0.196	0.196
36" pipe	0.00518	250	1.296	0.196	0.254
Contraction			0.25	0.196	0.049
24" pipe	0.00889	500	4.45	1.0	4.45
Exit	-	-	1.0	1.0	1.0
					5.949

5. **Discharge**

$$Q = 3.14\sqrt{\frac{(2)(32.2)(100)}{5.949}}$$

$$= 103 \text{ cfs}$$

HYDRAULICS OF CULVERTS(2)

There are two major types of culvert flow: 1) Flow with inlet control, and 2) flow with outlet control. For each type, different factors and formulas are used to compute the hydraulic capacity of the culvert. Under inlet control, the slope, roughness and diameter of the culvert barrel, the inlet shape and the amount of headwater or ponding at the entrance must be considered. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the length of the culvert.

The need for making involved computations to determine the probable type of flow under which a culvert will operate may be avoided by computing headwater depths from Exhibits 3-9 through 3-12 for both inlet control and outlet control and then using the higher value for design.

Both inlet control and outlet control types of flow are discussed briefly in the following paragraphs.

Culverts Flowing With Inlet Control

Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HW) and the shape of the entrance. Figure 3-7 shows inlet control flow for three types of culvert entrances.

In inlet control the length of the culvert barrel and outlet conditions are not factors in determining culvert capacity.

In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools, the water surface and the energy line at the entrance are assumed to coincide.

Headwater-discharge relationships for various types of circular culverts flowing with inlet control are based on laboratory research with models and verified in some instances by full-scale tests. Exhibits 3-9 and 3-10 give headwater-discharge relationships for round concrete and CM pipe culverts flowing with inlet control.

Example 3-16

It is desired to determine the maximum discharge of an existing 42-inch concrete culvert. The allowable headwater depth (HW) upstream is 8.0 feet and the slope of the culvert is 0.02 ft/ft. The culvert has a projecting entrance condition and there will be no backwater from downstream flow. Assume inlet control.

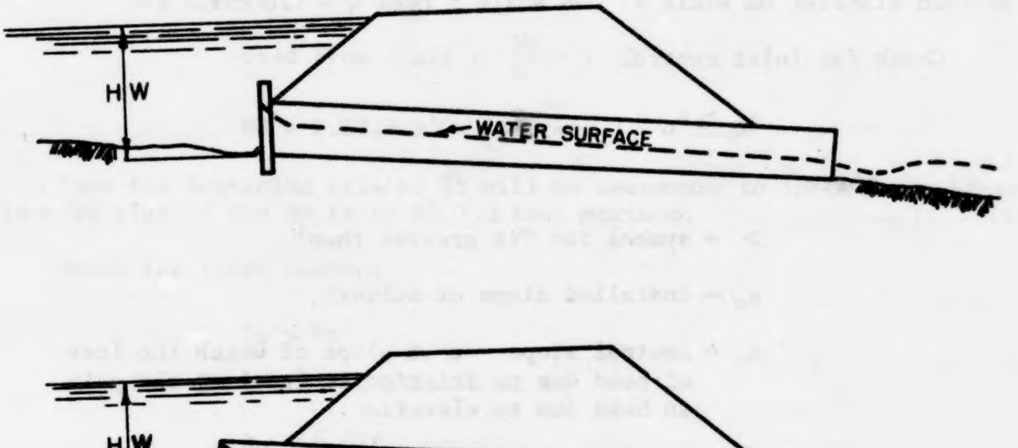

HW
WATER SURFACE
HW
WS
HW
WS

Figure 3-7 Culverts with inlet control

Using Exhibit 3-9, compute $\frac{HW}{D}$

$$\frac{HW}{D} = \frac{8(12)}{42} = 2.29$$

At 2.29 on scale 3, projecting entrance, draw a horizontal line to scale 1. From this point on scale 1 draw a connecting line between it and 42-inch diameter on scale 4. On scale 5 read Q = 128 cfs.

Check for inlet control

$$s_o > s_n$$

where

> = symbol for "is greater than"

s_o = installed slope of culvert

s_n = neutral slope - that slope of which the loss of head due to friction is equal to the gain in head due to elevation.

from Table 3-1, n(design) for concrete pipe = 0.012

from Exhibit 3-5, sheet 3 of 6

for Q = 128 cfs and D = 42 inches

$s_n = 0.013$

therefore, the culvert is in inlet control, $0.02 > 0.013$

Example 3-17

Determine the required diameter of a corrugated metal culvert pipe to be installed in an existing channel. Q = 100 cfs, HW max. = 7.0 feet and $s_o = 0.03$. There will be no backwater from downstream flow. Entrance to be mitered to conform to the slope of the embankment.

The solution of this problem must be made by trial pipe diameters and solution of HW by use of Exhibit 3-10.

Try D = 36"

draw a line through 36 inch on scale 4 and 100 cfs on scale 5 to an intersection with scale 1, then a horizontal line from scale 1 to scale 2, mitered inlet. On scale 2 read $\frac{HW}{D} = 3.8$,

then HW = 3.8(3) = 11.4 feet too high

Try D = 48"

read from scale 2, $\frac{HW}{D} = 1.45$

$HW = 1.45(4) = 5.80$ feet low

Try D = 42"

read from scale 2, $\frac{HW}{D} = 2.23$

$HW = 2.23(3.5) = 7.8$ feet high

From the foregoing trials, it will be necessary to install the 48-inch diameter pipe if the HW is to be 7.0 feet maximum.

Check for inlet control

$s_o > s_n$

from Exhibit 3-5, sheet 6 of 6

$s_n = 0.017$

$0.03 > 0.017$ therefore, inlet control

Culverts Flowing With Outlet Control

Culverts flowing with outlet control can flow with the culvert barrel full for all or part of the barrel length. See Figure 3-8. If the entire cross section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow, Figure 3-8(a) and (b). One other type of outlet control is shown in Figure 3-8(c). For this condition, the elevation of the energy gradeline at the exit of the culvert is assumed at 3/4D. This is not an exact figure but it will give reasonable results.

The head, H, Figure 3-8(a), or energy required to pass a given quantity of water through a culvert with outlet control is made up of three parts. The parts are expressed in feet of water and include a velocity head, H_v, an entrance loss, H_e, and a friction loss, H_f. This energy is obtained from ponding of water at the entrance and is expressed by the equation

$$H = H_v + H_e + H_f \qquad \text{(Eq. 3-13)}$$

This equation in similar form has been derived in the section on Hydraulics of pipelines.

The entrance loss, H_e, depends upon the shape of the inlet edge. This loss is expressed as a coefficient, K_e, times the barrel velocity head. That is, $H_e = K_e \frac{v^2}{2g}$. Entrance loss coefficients, K_e, for various types of entrances when flow is in outlet control are given in Table 3-3.

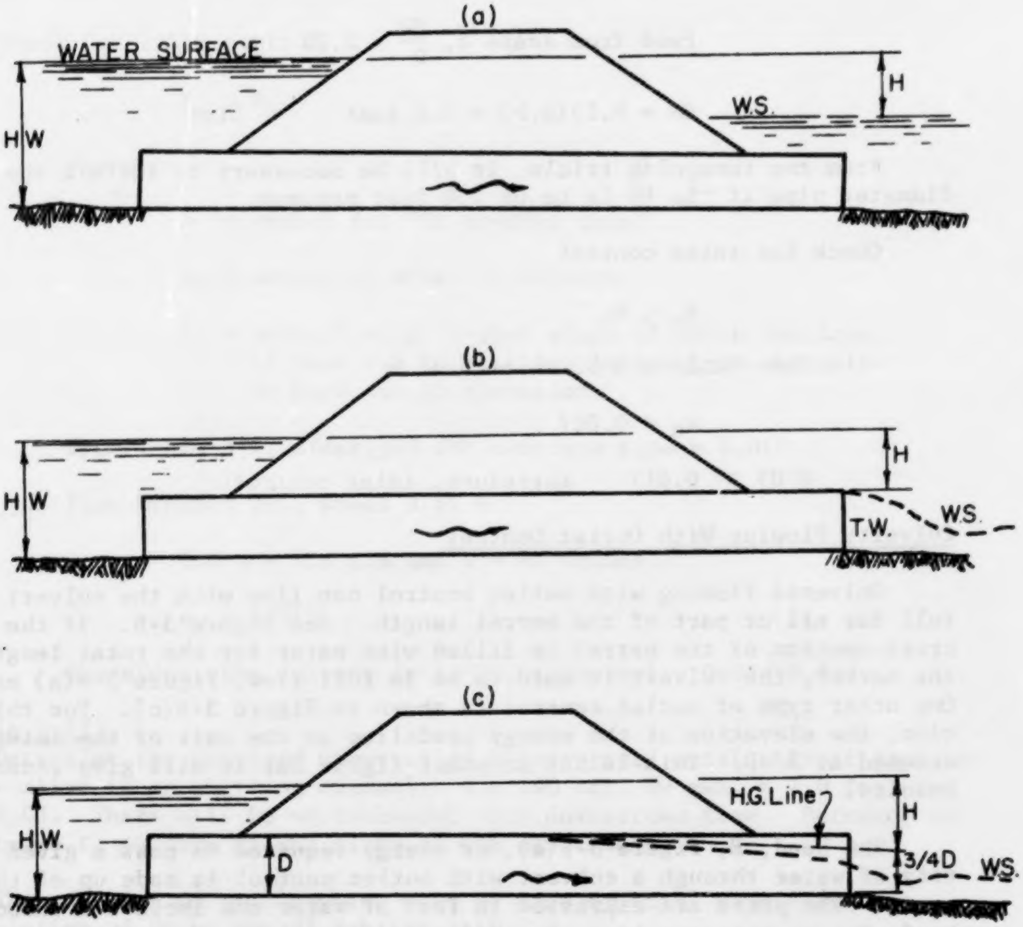

(a)
WATER SURFACE
H
W.S.
HW
(b)
H
HW
W.S.
T.W.
(c)
HW
H.G. Line
H
D
3/4D
W.S.

Figure 3-8 Culverts with outlet control

Table 3-3 Entrance Loss Coefficients

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-end	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
*End-section conforming to fill slope	0.5

Note: *"End-section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control.

The friction loss, H_f, is the energy required to overcome the roughness of the culvert barrel and is expressed by the equation

$$H_f = K_p L \frac{v^2}{2g}$$

K_p values can be taken from Exhibit 3-4.

Headwater depth can be expressed as an equation for all outlet control conditions, including all depths of tailwater, TW. This is done by designating the vertical distance from the culvert invert at the outlet to the elevation from which H is measured as h_o.

$$HW = H + h_o - s_o \ell \qquad \text{(Eq. 3-14)}$$

where ℓ = length of culvert
s_o = slope of culvert in feet per foot
H = head loss in feet as determined from the appropriate exhibit

When the elevation of the water surface in the outlet channel is equal to or above the top of the culvert opening at the outlet, Figure 3-9(a), h_o is equal to the tailwater depth. If the tailwater elevation is below the top of the culvert opening at the outlet, Figure 3-9(b), h_o, is then by definition 3/4D.

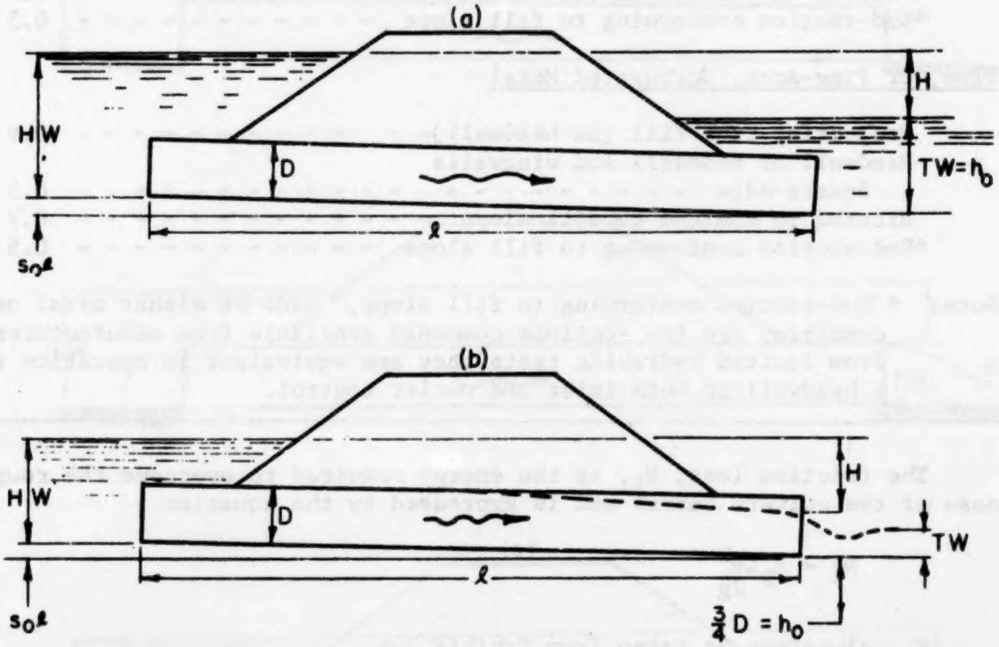


Figure 3-9 Culvert water depth relationships

Headwater-discharge relationships for various types of circular culverts flowing with outlet control may be solved by the use of Exhibits 3-11 and 3-12. For a different roughness coefficient n_1 than that of the exhibit n, use the length scales shown with an adjusted length, ℓ_1, calculated by the formula

$$\ell_1 = \ell\left(\frac{n_1}{n}\right)^2$$

Example 3-18

It is desired to install 50 feet of concrete culvert pipe, $n = 0.012$, in a drainage channel for a road crossing. Design Q is 80 cfs with a tailwater depth of 3.0 feet. Slope of the culvert will be 0.002 foot per foot. Maximum headwater depth (HW) is 5 feet.

from Equation 3-14

$HW = H + h_o - s_o\ell$ or, $H = HW - h_o + s_o\ell$

$H = 5.0 - 3.0 + .002(50)$

$H = 2.1$ feet

and from Table 3-3

for a concrete pipe projecting from the fill with socket end upstream

$K_e = 0.2$

entering Exhibit 3-11

draw a line between $H = 2.1$ feet on the head scale and $Q = 80$ cfs on the discharge scale. Then on the length scale for $K_e = 0.2$, draw a second line from the 50-feet mark through the intersection of the first line with the "turning line" and on to the pipe diameter scale. The diameter scale intersection is at approximately 39 inches, therefore, use a 42-inch pipe.

Erosive Culvert Exit Velocities

A culvert, because of its hydraulic characteristics, increases the velocity of flow over that in the adjacent channel. High velocities may be damaging just downstream from the culvert outlet and the erosion potential at this point should be considered in culvert design. In many cases it is necessary to riprap the channel for a short distance downstream of the culvert exit.

6. OPEN CHANNEL FLOW

The flow of water in an open channel differs from pipe flow in one important respect. See Figure 3-5. Open channel flow must have a free water surface, whereas pipe flow has none since water must fill the whole conduit.

Flow calculations for open channels are complicated by the fact that the position of the water surface is likely to change with respect to time and the cross-sectional area. Also the depth of flow, discharge, and slopes of the channel bottom and water surface are interdependent. Channel cross sections can vary from semicircular to the irregular forms of natural streams. The channel surface may vary from that of polished metal used in testing flumes to that of rough, irregular riverbeds. Moreover, the roughness in an open channel varies with the position of the free water surface. Therefore, the proper selection of friction coefficients is more uncertain for open channels than for pipes. In general, the treatment of open channel flow is somewhat more empirical than that of pipe flow, but the empirical method is the best available. If cautiously applied, it results in practical values.

TYPES OF CHANNEL FLOW

Open channel flow can be classified according to the change in flow depth with respect to the time interval being considered and the channel cross-sectional area occupied by the flow.

1. **Steady flow**
    - a. **Uniform flow**
    - b. **Nonuniform flow**
        - (1) **Gradually varied flow**
        - (2) **Rapidly varied flow**
2. **Unsteady flow**
    - a. **Unsteady uniform flow (rare)**
    - b. **Unsteady varied flow**
        - (1) **Gradually varied unsteady flow**
        - (2) **Rapidly varied unsteady flow**

Steady Flow and Unsteady Flow: Based on Time Interval

Flow in an open channel is steady if the depth of flow at a given cross section does not change, or if it can be assumed to be constant, during the time interval being considered. The flow is unsteady if the depth of flow at a given cross section changes with time.

In most open-channel problems it is necessary to study flow behavior only under steady conditions. If, however, the change in flow condition with respect to time is of major concern, the flow should be treated as unsteady. In floods and surges, for instance, which are typical examples of unsteady flow, the stage of flow changes instantaneously as the waves pass by, and the time element becomes important in the design of control structures.

Uniform Flow and Nonuniform Flow: Based on Channel Space Used

Open-channel flow is uniform if the depth of flow is the same at every section of the channel. A uniform flow may be steady or unsteady, depending on whether or not the depth changes during the time period being considered.

Steady uniform flow is the basic type of flow treated in open-channel hydraulics. The depth of the flow does not change during the time interval under consideration. Unsteady uniform flow means that the water

surface fluctuates from time to time while remaining parallel to the channel bottom, which is practically impossible.

Flow is nonuniform if the depth of flow changes along the length of the channel. Nonuniform flow may be either steady or unsteady.

Nonuniform flow may be classed as either rapidly or gradually varied. The flow is rapidly varied if the depth changes abruptly over a comparatively short distance; otherwise, it is gradually varied. Examples of rapidly varied flow are the hydraulic jump and the hydraulic drop.

Various types of flow are shown in Figure 3-10.

CHANNEL CROSS-SECTION ELEMENTS

The elements of cross sections of an open channel required for hydraulic computations are:

a, the cross-sectional area of flow;

p, the wetted perimeter, that is, the length of the boundary of the cross section in contact with the water;

$r = \frac{a}{p}$, the hydraulic radius, which is the cross-sectional area of the stream divided by the wetted perimeter.

General formulas for determining area, wetted perimeter, hydraulic radius, and top widths of trapezoidal, rectangular, triangular, circular, and parabolic sections are given in Exhibit 3-13. Many tables are available showing hydraulic elements for various sizes and shapes of channels. The USDI Bureau of Reclamation "Hydraulic and Excavation Tables"(3) and Corps of Engineers "Excavation Tables"(4) are good books if there is much of this work to be done.

MANNING'S EQUATION

The most widely used open channel formulas express mean velocity of flow as a function of the roughness of the channel, the hydraulic radius, and the slope of the energy gradient. They are equations in which the values of constants and exponents have been derived from experimental data. Manning's equation is one of the most widely accepted and commonly used of the open channel formulas:

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} \qquad \text{(Eq. 3-15)}$$

v = mean velocity of flow in feet per second

r = hydraulic radius in feet

s = slope of the energy gradient

s_o = slope of channel bottom

n = coefficient of roughness

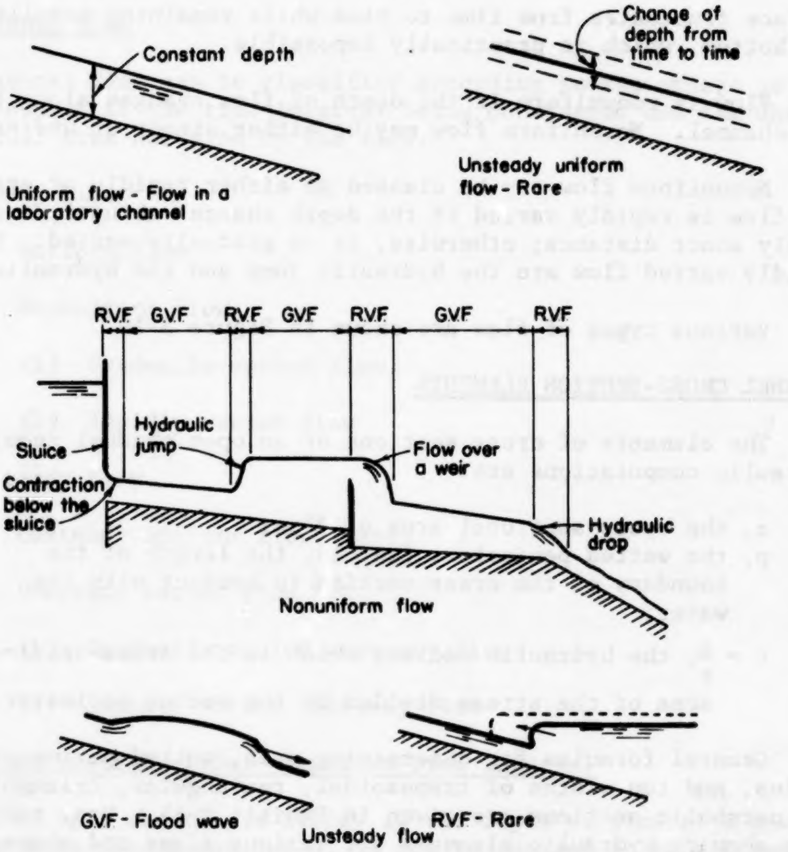

Constant depth
Uniform flow - Flow in a laboratory channel
Change of depth from time to time
Unsteady uniform flow - Rare
R.V.F.
G.V.F.
R.V.F.
G.V.F.
R.V.F.
G.V.F.
R.V.F.
Sluice
Hydraulic jump
Contraction below the sluice
Flow over a weir
Hydraulic drop
Nonuniform flow
G.V.F - Flood wave
R.V.F - Rare
Unsteady flow

Figure 3-10 Various types of open-channel flow. G.V.F. = gradually varied flow; R.V.F. = rapidly varied flow.

Manning's equation has the advantage of simplicity and gives values of velocity consistent with experimental data. Exhibit 3-14, sheets 1 through 4, may be used to solve for v, r, s, and n when any three are known.

Since Q = av, Manning's equation may also be written:

$$Q = \frac{1.486}{n} a r^{2/3} s^{1/2} \qquad \text{(Eq. 3-16)}$$

where a = cross-sectional area in square feet.

There are many other forms of Manning's equation which are developed by algebraic changes(1) to solve for various elements when the other elements are known. These forms should be studied carefully. Having mastered the use of the formula, the tables, nomographs and charts can be used with confidence.

Coefficient of Roughness, n

The computed discharge for any given channel or pipe will be only as reliable as the estimated value of n used in making the computation. This estimate affects the design discharge capacity and the cost, and therefore, requires careful consideration.

In the case of pipes and lined channels, this estimate is easier to make but it should be made with care. A given situation will afford specific information on such factors as size and shape of cross section, alignment of the pipe or channel, and the type and condition of the material forming the wetted perimeter.

Knowledge of these factors, along with the results of experimental investigations and experience, makes possible selections of n values within reasonably well-defined limits.

Natural channels and excavated channels, subject to various types and degrees of change, present a more difficult problem. The selection of appropriate values for design of drainage, irrigation, and other excavated channels is covered by manual data relating to those subjects.

The value of n is influenced by several factors; those having the greatest influence are:

Physical Roughness

The types of natural material forming the bottom and sides and the degree of surface irregularity are the guides to evaluation. Soils made up of fine particles on smooth, uniform surfaces result in relatively low values of n. Coarse materials, such as gravel or boulders, and pronounced surface irregularity cause higher values of n.

Vegetation

The value of n should be an expression of the retardance to flow as it will be affected by height, density, and type of vegetation. Consideration should be given to density and distribution of the vegetation along the reach and the wetted perimeter; the degree to which the vegetation occupies or blocks the cross-sectional area of flow at different depths; and the degree to which the vegetation may be bent or the channel "shingled" by flows of different depths.

Cross Section

Gradual and uniform increases or decreases in cross-section size will not significantly affect n, but abrupt changes in size or the alternating of small and large sections call for the use of a somewhat larger n. Uniformity of cross-sectional shape will cause relatively little resistance to flow; whereas variation, particularly if it causes meandering of the major part of the flow from side to side of the channel, will increase n.

Channel Alignment

Curves with a relatively large radius and without frequent changes in direction of curvature will offer comparatively low resistance to flow. Severe meandering with the curves having relatively small radii will significantly increase n.

Silting or Scouring

Whether either or both of these processes are active, and whether they are likely to continue or develop in the future, is important. Active silting or scouring, since they result in channel variation of one form or another, will tend to increase n.

Obstructions

Log jams and deposits of any type of debris will increase the value of n; the degree of effect is dependent on the number, type, and size of obstructions.

The value of n, in a natural or constructed channel in earth, varies with the season and from year to year; it is not a fixed value. Each year n increases in the spring and summer as vegetation grows and foliage develops, and diminishes in the fall as the dormant season develops. The annual growth of vegetation, uneven accumulation of sediment in the channel, lodgment of debris, erosion and sloughing of banks, and other factors all tend to increase the value of n from year to year until the hydraulic efficiency of the channel is improved by clearing or clean-out.

All of these factors should be studied and evaluated with respect to kind of channel, degree of maintenance, seasonal requirements, season of the year when the design storm normally occurs, and other considerations as a basis for selecting the value of n. As a general guide to judgment, it can be accepted that conditions tending to induce turbulence will increase retardance. Refer to Chapters 7 and 14 of this manual for guidance in selecting retardance and n values.

SPECIFIC ENERGY IN CHANNELS

The specific energy equation is used to solve many open channel problems such as water surface profiles upstream of culverts and channel junctions and the water surface profile in a chute spillway.

Figure 3-11 shows a section of channel in uniform flow. Here, for a given slope, roughness, cross section and rate of flow, the depth may be calculated from the Manning equation.

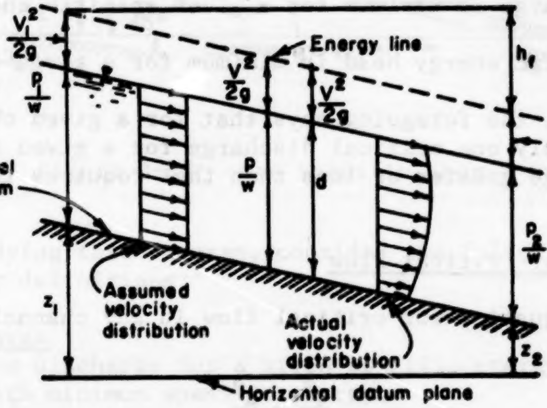

$\frac{V_1^2}{2g}$
$\frac{P_1}{w}$
Energy line
$\frac{V^2}{2g}$
$\frac{V^2}{2g}$
h_f
$\frac{V_2^2}{2g}$
Channel bottom
$\frac{P}{w}$
d
$\frac{P_2}{w}$
z_1
Assumed velocity distribution
Actual velocity distribution
z_2
Horizontal datum plane

Figure 3-11 Channel energy relationships

Assuming a uniform velocity distribution, the Bernoulli equation may be written for a typical reach of channel as:

$$\frac{P_1}{w} + \frac{v_1}{2g} + z_1 = \frac{P_2}{w} + \frac{v_2^2}{2g} + z_2 + hf$$

which shows that energy is lost as flow occurs. However, the distance from channel bottom to energy line remains constant and is given by

$$H_e = y + \frac{P}{w} + \frac{V^2}{2g} = d + \frac{V^2}{2g} \qquad \text{(Eq. 3-17)}$$

in which H_e is known as the specific energy. Obviously the specific energy in an open channel is the sum of the water depth and the velocity head.

The following section on critical flow illustrates another application of the specific energy equation to solve channel flow problems.

CRITICAL FLOW CONDITIONS

Critical flow is the term used in open channel flow to define a dividing point between subcritical (tranquil) and supercritical (rapid) flow. At this point there exists certain relationships between specific energy and discharge and specific energy and depth of flow. As shown previously, specific energy is the total energy head at a cross section measured from the bottom of the channel. There are two conditions which describe critical flow:

1. The discharge is maximum for a given specific energy head.

2. The specific energy head is minimum for a given discharge.

Stated simply, the foregoing says that for a given channel section there is one and only one critical discharge for a given specific energy head. Any discharge greater or less than that requires the addition of specific energy.

General Equation for Critical Flow

The general equation for critical flow in any channel is

$$\frac{Q^2}{g} = \frac{a^3}{T} \qquad \text{(Eq. 3-18)}$$

From Equation 3-18, $\frac{Q^2}{a^2} = \frac{ag}{T}$: and since $\frac{Q^2}{a^2} = v^2$ and

$a = d_m T$, the specific energy equation when flow is critical is

$$H_e = d + \frac{a}{2T} = d + \frac{d_m}{2} \qquad \text{(Eq. 3-19)}$$

where: Q = total discharge
a = cross-sectional area
d = depth of flow to the bottom of the section
d_m = a/T = mean depth of flow
g = acceleration of gravity
H_e = specific energy head, i.e., the energy head referred to the bottom of channel
T = top width of the stream
v = mean velocity of flow

A study of the specific energy diagram, Figure 3-12, will give a more thorough understanding of the relationships between discharge, energy, and depth when flow is critical.

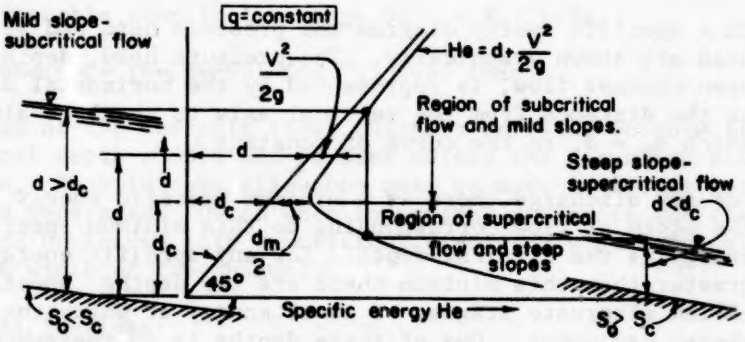

Mild slope-
subcritical flow
q= constant
$\frac{V^2}{2g}$
$He = d + \frac{V^2}{2g}$
Region of subcritical flow and mild slopes.
d
d >d_c
d
d
d_c
d_c
$\frac{d_m}{2}$
45°
Steep slope-
supercritical flow
d<d_c
Region of supercritical flow and steep slopes
$S_0 < S_c$
Specific energy He
$S_0 > S_c$

Figure 3-12 The Specific Energy Diagram

While studying this diagram, consider the following critical flow terms and their definitions:

Critical Discharge

The maximum discharge for a given specific energy, or a discharge which occurs with minimum specific energy.

Critical Depth

The depth of flow at which the discharge is maximum for a given specific energy, or the depth at which a given discharge occurs with minimum specific energy.

Critical Velocity

The mean velocity when the discharge is critical.

Critical Slope

That slope which will sustain a given discharge at uniform, critical depth in a given channel.

Subcritical Flow

Those conditions of flow for which the depth is greater than critical and the velocity is less than critical.

Supercritical Flow

Those conditions of flow for which the depth is less than critical and the velocity is greater than critical.

The curve shows the variation of specific energy with depth of flow for a constant Q in a channel of a given cross section. Similar curves for any discharge at a section of any form may be obtained from Equation 3-17. Certain points, as illustrated by this curve, should be noted:

1. In a specific energy diagram the pressure head and velocity head are shown graphically. The pressure head, depth in open channel flow, is represented by the horizontal scale as the distance from the vertical axis to the line along which $H_e = d$, to the curve of constant Q.
2. For any discharge there is a minimum specific energy, and the depth of flow corresponding to this minimum specific energy is the critical depth. For any specific energy greater than this minimum there are two depths, sometimes called alternate stages, of equal energy at which the discharge may occur. One of these depths is in the subcritical range and the other is in the supercritical range.
3. At depths of flow near the critical for any discharge, a minor change in specific energy will cause a much greater change in depths.
4. Through the major portion of the subcritical range the velocity head for any discharge is relatively small when compared to specific energy, and changes in depth are approximately equal to changes in specific energy.
5. Through the supercritical range the velocity head for any discharge increases rapidly as depth decreases, and changes in depth are associated with much greater changes in specific energy.

Instability of Critical Flow

The instability of uniform flow at or near critical depth is usually defined in terms of critical slope, s_c.

s_c = critical slope - that slope which will sustain a given discharge in a given channel at uniform, critical depth.

The critical slope, s_c, is:

$$s_c = 14.56 \frac{n^2 d_m}{r^{4/3}} \qquad \text{(Eq. 3-20)}$$

Uniform flow at or near critical depth is unstable. This results from the fact that the unique relationship between energy head and depth of flow which must exist in critical flow is readily disturbed by minor changes in energy. Those who have seen uniform flow at or near critical depth have observed the unstable wavy surface that is caused by appreciable changes in depth resulting from minor changes in energy. This unstable range is defined as follows:

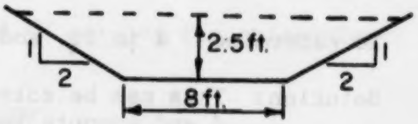
Unstable zone in the range $0.7s_c < s_o < 1.3s_c$

where $<$ = the symbol for "is less than"

Because of the unstable flow, channels carrying uniform flow at or near critical depth should not be used unless the situation allows no alternative. In this case allowance must be made in design for the height of the wave generated. Often when topography restricts the channel slope the flow can be forced into subcritical stable or supercritical stable by varying the width of the channel.

Open Channel Problems

Example 3-19



Given: Trapezoidal section

n = 0.02
s = 0.006

To determine: Q in cfs, and v in fps

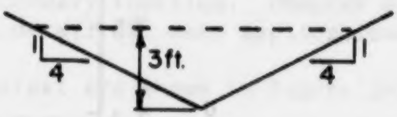
Solution: from Exhibit 3-13

$$r = \frac{a}{P} = \frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}} = \frac{8(2.5) + 2(2.5)^2}{8 + 2(2.5)\sqrt{(2)^2 + 1}} = 1.695$$

enter Exhibit 3-14 with r = 1.695, s = 0.006, n = 0.02, and read v = 8.19 fps

then Q = av = 32.5(8.19) = 266 cfs

Example 3-20



Given: Triangular section

n = 0.025
s = 0.006

To determine: Q in cfs and v in fps

Solution: from Exhibit 3-13

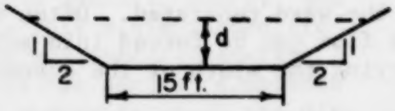
$$r = \frac{a}{p} = \frac{zd}{2\sqrt{z^2 + 1}} = \frac{4(3)}{2\sqrt{(4)^2 + 1}} = \frac{12}{8.246} = 1.455$$

enter Exhibit 3-14 with $r = 1.455$, $s = 0.006$, $n = 0.025$ and read $v = 5.91$ fps

then $Q = av = 36(5.91) = 213$ fps

Example 3-21

Given: Trapezoidal section



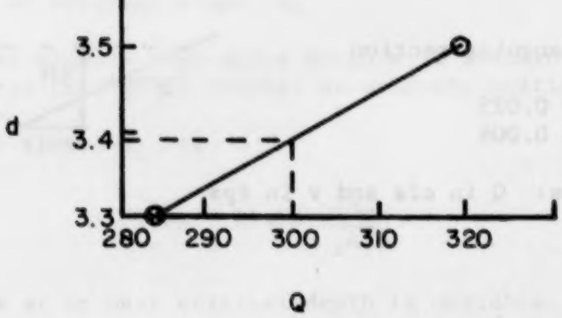
$Q = 300$ cfs
$n = 0.02$
$s = 0.0009$

To determine: d in ft. and v in ft/sec.

Solution: This can be solved by trial. First, assume a value for d and compute the values of a, p, r; then from Exhibit 3-14 find v and compute Q.

Trial	d	a	p	r	v	Q
1	3.0	63.0	28.42	2.21	3.80	239.4
2	3.5	77.0	30.65	2.51	4.14	318.8
3	3.3	71.3	29.76	2.39	3.98	283.8

Plot d against Q for trial 2 and 3 and read $d = 3.39$ ft., for $Q = 300$ cfs



For those having much of this work to do, the use of tables in King's Handbook, based on the equation $K' = \dfrac{Qn}{b^{8/3}\ s^{1/2}}$, will provide rapid direct solutions, i.e.,

$$b = 15^{8/3} = 1370 \text{ and } s^{1/2} = .009^{1/2} = 0.03$$

$$\text{then } K' = \frac{(300)(.02)}{(1370)(.03)} = 0.146$$

From the table of K' values for 2:1 sides and K' = 0.146

$$\frac{D}{b} = 0.226$$

$$D = (15)(0.226) = 3.39 \text{ feet}$$

The same procedures can be followed in solving for triangular sections.

7. WEIR FLOW

A weir is a notch of regular form through which water flows. The structure containing the notch is also called a weir. The edge over which the water flows is the crest of the weir. Two types of weir crests are common in soil conservation work, sharp-crested weirs and broad-crested weirs.

The sharp-crested weir is used only to measure the discharge of a channel or stream. The sharp edge causes the water to spring clear of the crest.

Most hydraulic structures in soil conservation work have broad-crested weirs. The crest is horizontal and long in the direction of flow so that the water lays on the crest rather than springing clear. The primary use of the broad-crested weir is for the control of flood flows, although water measurement can be incorporated as a secondary function. Chapter 6, Structures, of this manual describes in detail its many applications.

Examples of the two types of weir crest are shown in Figure 3-13 and 3-14.

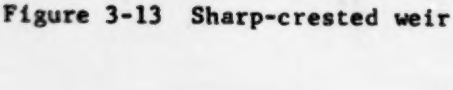


Figure 3-13 Sharp-crested weir

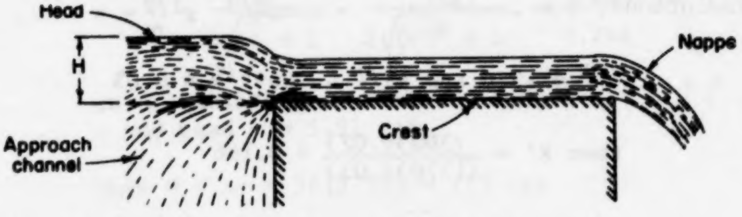


Figure 3-14 Broad-crested weir

If the overflowing sheet of water (nappe) discharges into the air, as above, the weir has free discharge. If the discharge is partially under water, as shown in Figure 3-15, the weir is submerged or drowned.

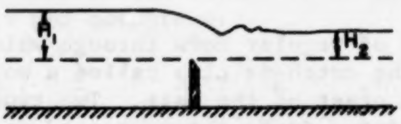


Figure 3-15 Submerged weir

BASIC EQUATION

The basic equation for all weirs is:

$$Q = CLH^{3/2} \qquad \text{(Eq. 3-21)}$$

where:

Q = discharge
H = measured head
L = length of weir
C = weir coefficient

Corrections are required to include effects of end contractions, velocity of approach and submergence.

CONTRACTIONS

The weir is contracted when the respective distances from the sides and the bottom of the channel of approach to the sides and crest of the weir are great enough to allow the water free lateral approach to the crest. If the weir conforms to the sides of the approach channel above the crest and the channel sides extend downstream beyond the crest, thereby preventing lateral expansion of the nappe, the weir has end contractions suppressed.

End contractions reduce the effective length of a weir. To allow for end contractions, the length of weir in the basic equation is adjusted as follows:

$$L = L' - 0.1NH \qquad \text{(Eq. 3-22)}$$

where:

L = effective length of weir
L' = measured length of weir
N = number of contractions

The above equation is generally applied only for sharp-crested weirs in soil conservation work. For most broad-crested weirs the end contractions will be either fully or partially suppressed. For drop spillways the basic formula can be used without modifying for contraction effect.

VELOCITY OF APPROACH

The velocity of approach is the average velocity in the approach channel. It is measured at a distance of about 3H upstream from the weir. The velocity head is added to the measured head to determine the discharge. Therefore:

$$Q = CL\left(H + \frac{v^2}{2g}\right)^{3/2} \qquad \text{(Eq. 3-23)}$$

WEIR COEFFICIENTS

Values of the weir coefficient, C, varies with the type of crest used. Weir coefficients for sharp-crested weirs normally used in soil conservation work are given under the following section on water measurement. The weir coefficient for broad-crested weirs commonly used in soil conservation work is C = 3.1.

SUBMERGED FLOW

When a weir is submerged, Figure 3-15, the discharge will be less than for the head in free flow. The reduction in flow can be expressed in terms of the ratio of the upstream head, H_1, to the downstream head, H_2.

When the ratio of H_2/H_1 for sharp-crested weirs reaches 0.3 to 0.4, the discharge may be reduced by 5 to 10 percent. For H_2/H_1 ratios of 0.6 to 0.7, reductions of 20 to 40 percent may be expected.

There is no great reduction in discharge for broad-crested weirs until the ratio of H_2/H_1 reaches 0.67. Then the discharge reduces rapidly as the submergence increases. For values of H_2/H_1 from 0.75 to 0.85, reductions from 10 to 30 percent occur.

When appreciable submergence is to be encountered, accurate discharge can be computed only through the use of refined procedures.

8. WATER MEASURING

The purpose of this section is to outline the most commonly used water measuring methods. The hydraulic principle and equation of flow is given for most methods. For convenience, the subject is divided into open channel flow and pipe flow.

OPEN CHANNELS

The following methods of measurement apply to flows in open channels.

Orifices

An orifice is a hole of regular form through which water flows.

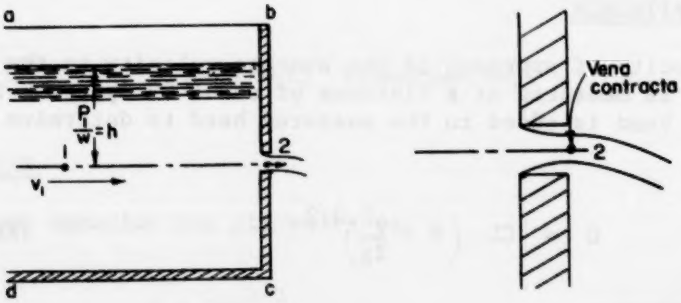


Figure 3-16 Flow through an orifice

Flow through an orifice is illustrated in Figure 3-16. The orifice shown is sharp-edged; i.e., it has a sharp upstream edge so that the water in passing touches only a line. If the orifice discharges into the air, it is said to have free discharge; and if it discharges under water, it is said to be submerged. Orifices may be circular, square, rectangular, or of any other regular form.

The Bernoulli equation written from point 1 to point 2, Figure 3-16, is

$$\frac{v_1^{\,2}}{2g} + \frac{P_1}{w} = \frac{v_2^{\,2}}{2g} + \frac{P_2}{w} + h_\ell$$

and

$$v2 = \sqrt{2g\left(\frac{P_1}{w} - \frac{P_2}{w} + \frac{v_1^{\,2}}{2g} - h_\ell\right)}$$

Point 2, located where the jet has ceased to contract is known as the vena contracta. Its pressure is that of the surrounding fluid. For discharge into the atmosphere P_2 is therefore zero on the gage scale. For large tanks, v_1 is so small that it may be neglected. Replacing P_1/w with h and dropping the subscript of v_2, the equation may now be written

$$v = \sqrt{2g(h - h_\ell)}$$

Neglecting energy losses, the equation for the theoretical velocity, v_t, becomes

$$v_t = \sqrt{2gh}$$

The energy loss may be taken care of by applying a coefficient of velocity C_v to the theoretical velocity as follows:

$$v = C_v \sqrt{2gh} \qquad \text{(Eq. 3-24)}$$

The discharge through an orifice is obtained from the product of the velocity and the area at the vena contracta. The area at the vena contracta, a_2, is less than the area of the orifice, a. The ratio between the two areas is called the coefficient of contraction C_c. Therefore,

$$a_2 = C_c a$$

and

$$Q = a_2 v_2 = C_c a C_v \sqrt{2gh}$$

The product of C_c and C_v is called the coefficient of discharge C. Equation for discharge may therefore be written

$$Q = Ca \sqrt{2gh} \qquad \text{(Eq. 3-25)}$$

The submerged orifice in Figure 3-17 is the type most often used in soil conservation work.

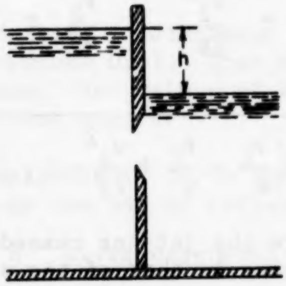


Figure 3-17 Submerged orifice

As in the free discharge orifice, Equations 3-24 and 3-25 also apply to the submerged orifice.

The coefficient of discharge for submerged orifices is approximately the same as that for free discharge orifices. The wide range in types of orifices and gates, a special form of orifice, makes it impractical to include tables of coefficients covering an adequate range of conditions. Manufacturers' publications are normally the best source of reliable coefficients for various types of gates and other appurtenances involving orifice flow.

Weirs

Sharp-crested weirs are used extensively for measuring the flow of water. The most common types--rectangular, Cipolletti, and 90° V-notch weirs--are shown in Figure 3-18.

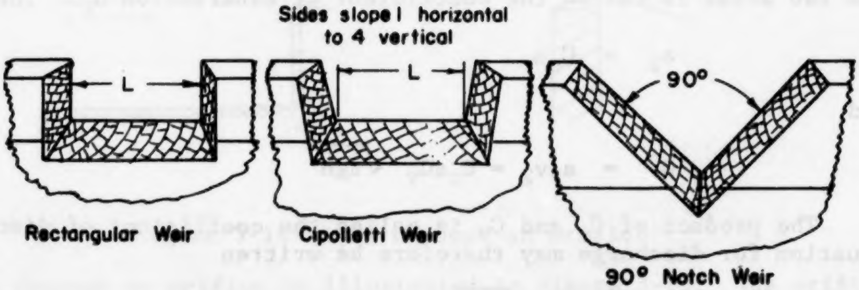


Figure 3-18 Types of weirs

As given in the preceding section, Weir Flow, the basic equation is

$$Q = CLH^{3/2}$$

Measurements made by means of a weir are accurate only when the weir is properly set and the head read at a point some distance above the crest so that the reading will not be affected by the downward curve of the water. See Figure 3-19. The weir should be at right angles to the stream at a point where the channel is straight, free from eddies and of sufficient width to produce full end contractions. The crest of the weir must be exactly level for the rectangular and Cipolletti types. The bottom of the notch must be set above the bottom of the channel a height equal to at least twice the maximum head, preferably more. If a weir is to continue to give reliable results, it must be maintained in such a way as to preserve the above-mentioned conditions.

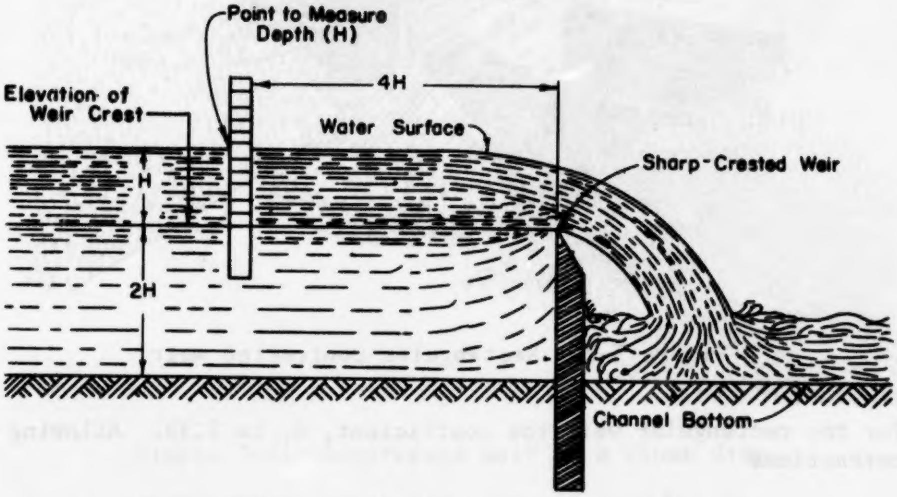

Point to Measure Depth (H)
4H
Elevation of Weir Crest
Water Surface
Sharp-Crested Weir
H
2H
Channel Bottom

Figure 3-19 Profile of a sharp-crested weir

Rectangular Contracted Weir

A rectangular contracted weir has its crest and sides so far removed, respectively, from the bottom and sides of the weir box or channel in which it is set, that full contraction, or reduced area of flow, is developed. See Figure 3-20.

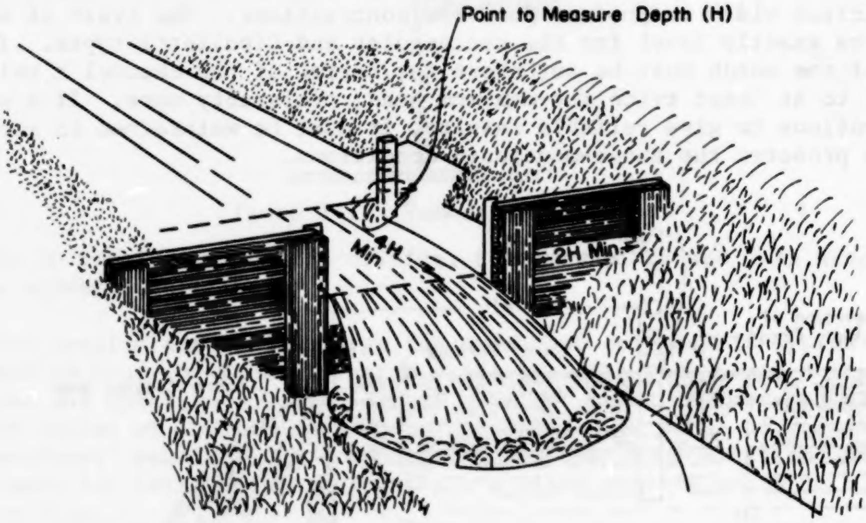


Figure 3-20 Rectangular contracted weir

For the rectangular weir the coefficient, C, is 3.33. Allowing for the contractions

$$Q = 3.33 H^{3/2} (L-0.2H)$$

where:

Q = discharge in cubic feet per second neglecting velocity of approach
L = the length of weir, in feet
H = head on the weir in feet measured at a point no less than 4 H upstream from the weir.

Discharges may be taken from Exhibit 3-15.

Rectangular Suppressed Weir

A rectangular suppressed weir has its crest so far removed from the bottom of the approach channel that full crest contraction is developed. The sides of the weir coincide with the sides of the approach channel which extend downstream beyond the crest and prevent lateral expansion of the nappe. A suppressed weir in a flume drop is illustrated in Figure 3-21.

Special care should be taken with this type of weir to provide aeration beneath the overflowing sheet at the crest. This is usually done by venting the underside of the nappe to the atmosphere at both sides of the weir box.

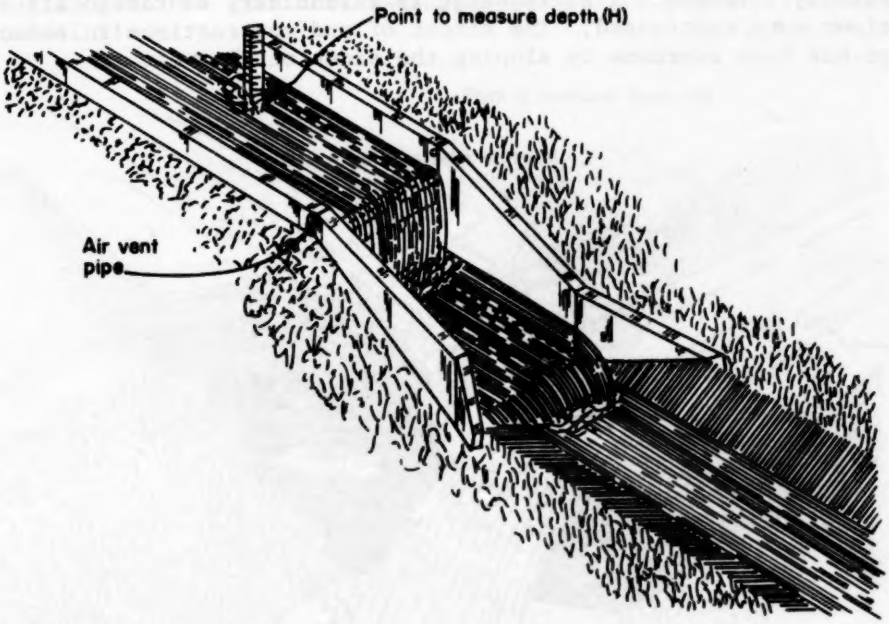


Figure 3-21 Suppressed weir in a flume drop

The discharge equation for the rectangular suppressed weir is

$$Q = 3.33\ L\ H^{3/2}$$

and including the velocity of approach

$$Q' = 3.33\ L \left((H + h_v)^{3/2} - h_v^{3/2} \right)$$

$$\text{where } h_v = \frac{(\text{velocity of approach})^2}{2g}$$

Discharge tables are available in the Bureau of Reclamation Water Measurement Manual, Table 8, pages 177 to 179.

Cipolletti Weir

A Cipolletti weir, Figure 3-22, is trapezoidal in shape. Its crest and sides, which are of thin plate, are so far removed from the bottom and sides of the approach channel as to develop full contraction of flow at the nappe. The sides incline outwardly at a slope of 1 to 4.

Since the Cipolletti weir is a contracted weir, it should be installed accordingly. However, its discharge is essentially as though its end contractions were suppressed. The effect of end contractions in reducing discharge has been overcome by sloping the sides of the weir.

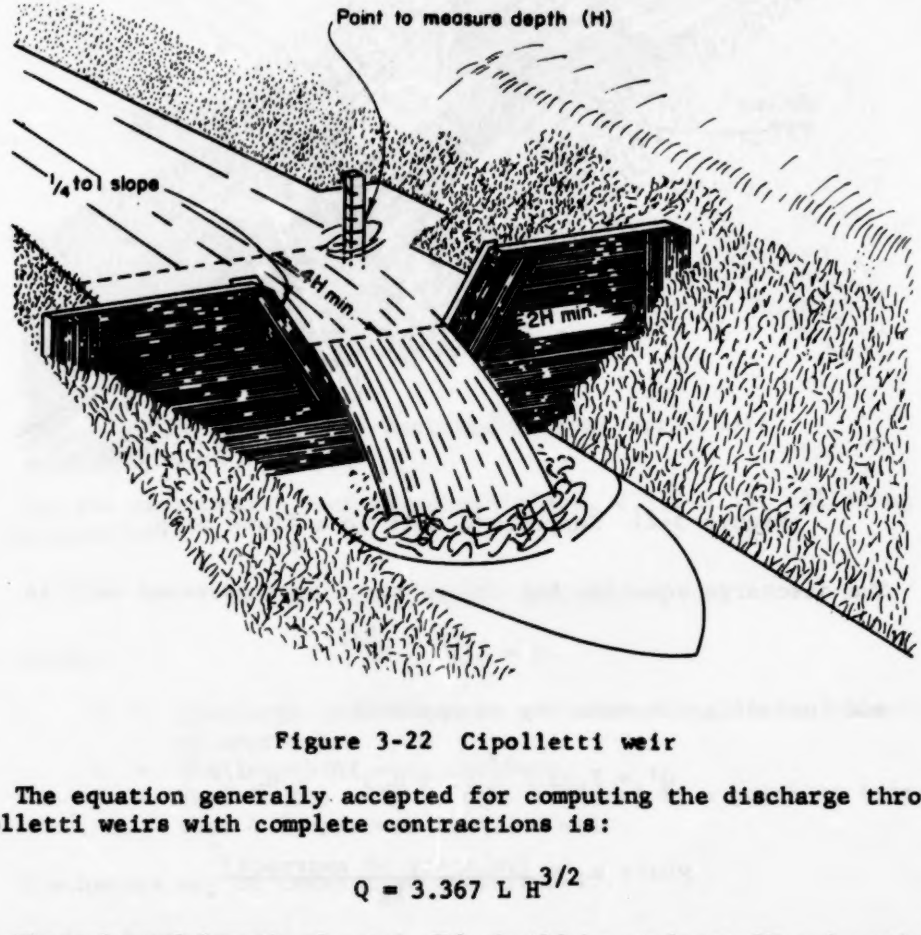

Point to measure depth (H)
¼ to 1 slope
4H min.
2H min.

Figure 3-22 Cipolletti weir

The equation generally accepted for computing the discharge through Cipolletti weirs with complete contractions is:

$$Q = 3.367 \; L \; H^{3/2}$$

The selected length of notch (L) should be at least 3H and preferably 4H or longer.

Discharges may be taken from Exhibit 3-16.

90° V-Notch Weir

The crest of the 90° V-notch weir consists of a thin plate, the sides of the notch being inclined 45° from the vertical. This weir has a contracted notch and all conditions for accuracy stated for the standard contracted rectangular weir apply. The minimum distance from the side of the weir to the channel bank should be measured horizontally from the point where the maximum water surface intersects the edge of the weir. The minimum bottom distance should be measured between the point of the notch and the channel floor.

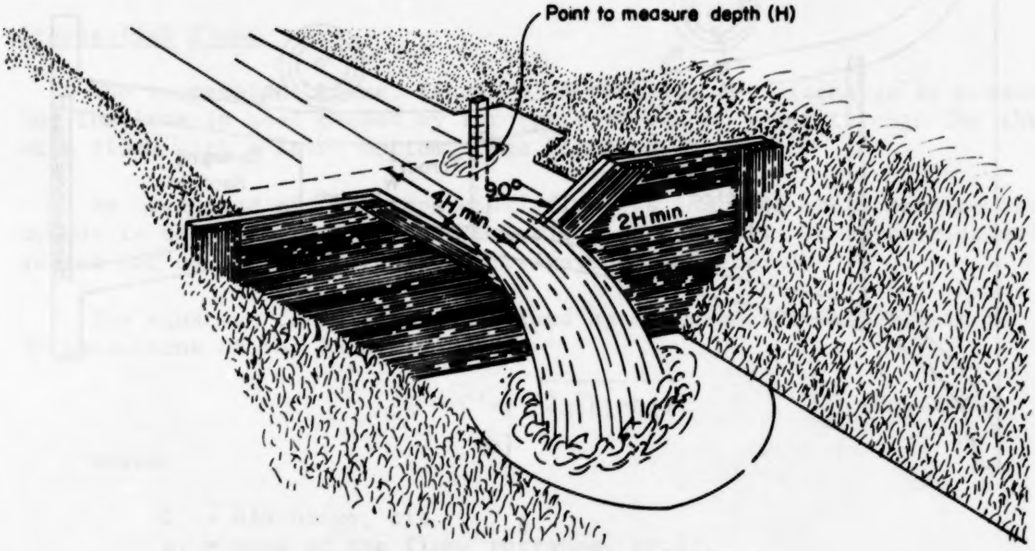


Figure 3-23 90° V-notch weir

The V-notch weir, Figure 3-23, is especially useful for measuring small discharges. The discharge equation used is

$$Q = 2.52H^{2.47}$$

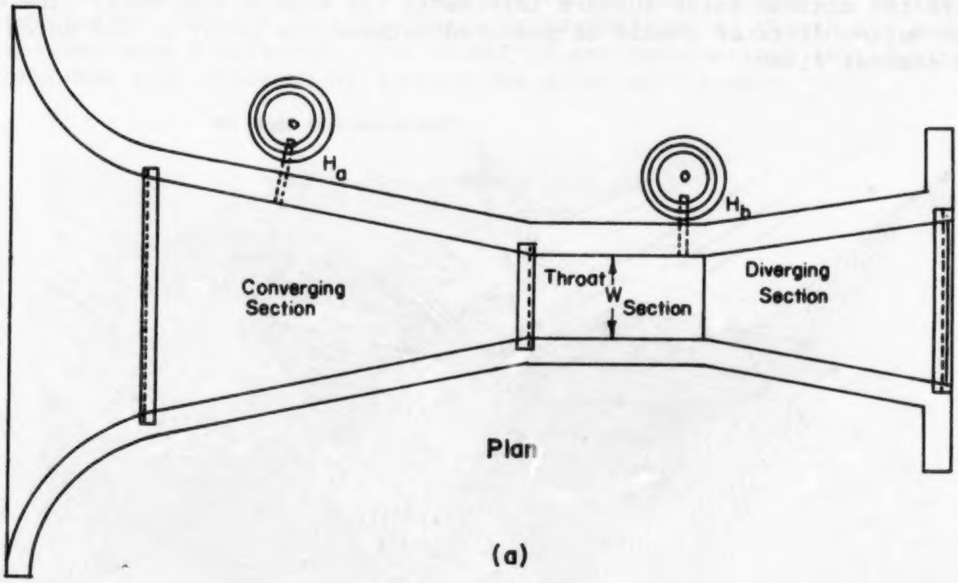
where

H = vertical distance in feet between the elevation of the vortex or lowest part of the notch and the elevation of the weir pond.

Exhibit 3-17 may be used for determining the discharge.

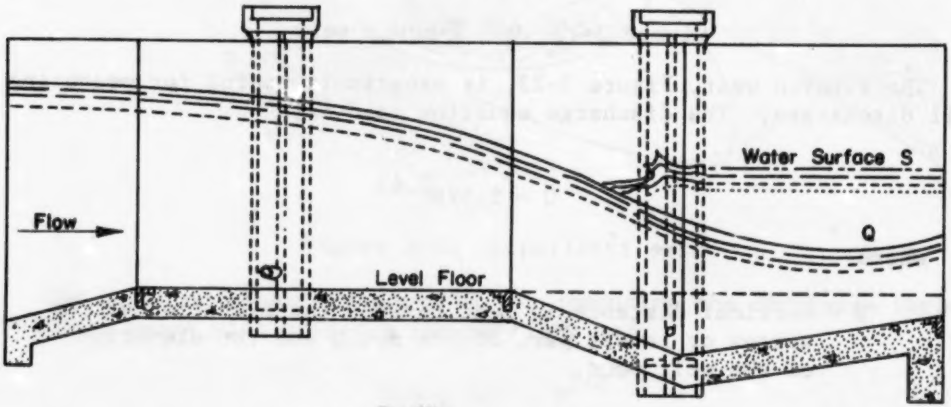
Parshall Flume

With a Parshall flume, Figure 3-24, the discharge is obtained by measuring the loss in head caused by forcing a stream of water through the throat section of the flume, which has a depressed bottom.


H_a
H_b
Converging Section
Throat
W
Section
Diverging Section

Plan

(a)


Water Surface S
Q
Flow
Level Floor

Profile

(b)

Figure 3-24 Parshall flume

There is no need of a pond above the Parshall flume as the velocity of approach has little effect on the accuracy of the measurement. It uses a small amount of head and can have a high degree of submergence without having to make corrections in the free-flow formula. It does not clog readily with floating trash and keeps itself clean of sand and silt. It requires but one reading of head (H_a) for determining the discharge except in cases of extreme submergence when both H_a and H_b should be read.

Table 9-14, Chapter 9, Section 15, of the National Engineering Manual gives free-flow discharge values for the Parshall flume.

Trapezoidal Flume

The trapezoidal flume, Figure 3-25, obtains the discharge by measuring the loss in head caused by forcing a stream of water through the throat of a flume with a level bottom. See Figure 3-25.

An advantage of the trapezoidal flume is that the cross section corresponds to the shape of the common irrigation channel. It is particularly suited for use in concrete lined irrigation channels.

The equation for discharge derived by Robinson and Chamberlain (Transactions of the ASAE, 1960) is

$$Q = C'a_1\sqrt{2g(h_1-h_2)} \qquad \text{(Eq. 3-29)}$$

where:

Q = discharge, cfs
a_1 = area at the flume entrance, sq.ft.
h_1 = head at the entrance, ft.
h_2 = head at the throat, ft.
C' = discharge coefficient that includes the geometry of the structure

Further information on the trapezoidal flume can be found in USDA Agricultural Research Service Bulletin 41-140, dated March 1968.

Current Meter

Basically, the current meter is a wheel having several cups or vanes. This wheel is rotated by the action of the current and the speed of the rotating wheel indicates the velocity of the current, based on a rating table furnished by the manufacturer.

A zero station or reference point is established on one bank of the stream, and a tape is stretched across the stream for measuring horizontal distances. Soundings and current-meter readings are taken at verticals spaced at regular intervals, usually from 2 to 10 feet, depending on the width of the stream. Readings also should be made where there are abrupt changes in velocity or in the depth of flow.

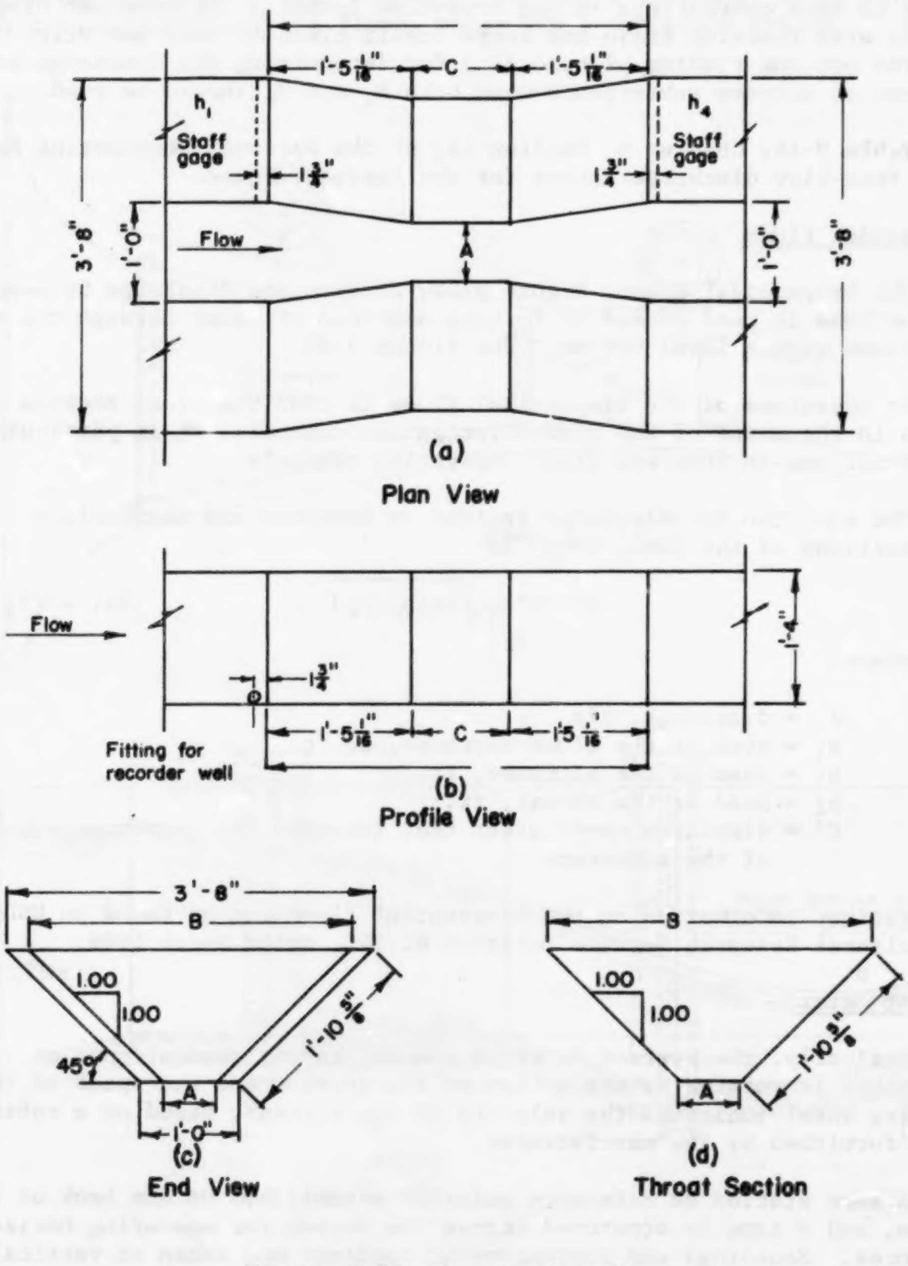

1'-5 1/16"
C
1'-5 1/16"
h1
Staff gage
1 3/4"
h4
Staff gage
1 3/4"
3'-8"
1'-0"
Flow
A
1'-0"
3'-8"
(a)
Plan View
Flow
1 3/4"
1'-4"
1'-5 1/16"
C
1'5 1/16"
Fitting for recorder well
(b)
Profile View
3'-8"
B
1.00
1.00
45°
1'-10 5/8"
A
1'-0"
(c)
End View
B
1.00
1.00
1'-10 5/8"
A
(d)
Throat Section

Figure 3-25 Trapezoidal flume

A common method used to determine mean velocity requires that readings be taken at only two points in each vertical; namely, 0.2 and 0.8 of the sounded depth measured from the water surface. The average of these two readings is the mean velocity in the vertical. Where the depth is too shallow to obtain two readings, one reading taken at 0.6 depth will represent the mean velocity.

The discharge of each segment of stream between adjacent verticals is the product of the area of the segment and the mean velocity in the segment. If d_1 and d_2 represent the depths of flow at two adjacent verticals, v_1 and v_2 the respective mean velocities in these verticals, and W the distance between the verticals, then the discharge in that part of the cross section is computed as follows:

$$Q = W\left(\frac{d_1 + d_2}{2}\right)\left(\frac{v_1 + v_2}{2}\right)$$

The total discharge of the stream is the sum of such computations for the entire cross section.

See Reference (1) for more detailed information.

Water-Stage Recorder

A water-stage recorder combines a clock and an instrument that draws a graph representing the rise and fall of a water surface with respect to time. Water-stage recorders are in common use at permanent gaging stations.

Water-stage recorders are desirable under the following conditions:

1. **The flow in the stream or channel fluctuates rapidly, and occasional staff-gage readings would not give a satisfactory estimate of discharge.**
2. **The gaging station is hard to get to, or the available observers are not reliable.**
3. **There is a need for continuous records of flow for legal or technical purposes.**

By the combined use of the stage-discharge curve (Figure 3-26) and the water-stage recorder, a hydrograph of the flow in a stream or channel may be plotted. A hydrograph is a curve developed by plotting discharge on a vertical scale against time plotted on a horizontal scale. The area beneath the curve represents the volume of water passing the gaging station during any selected time period.

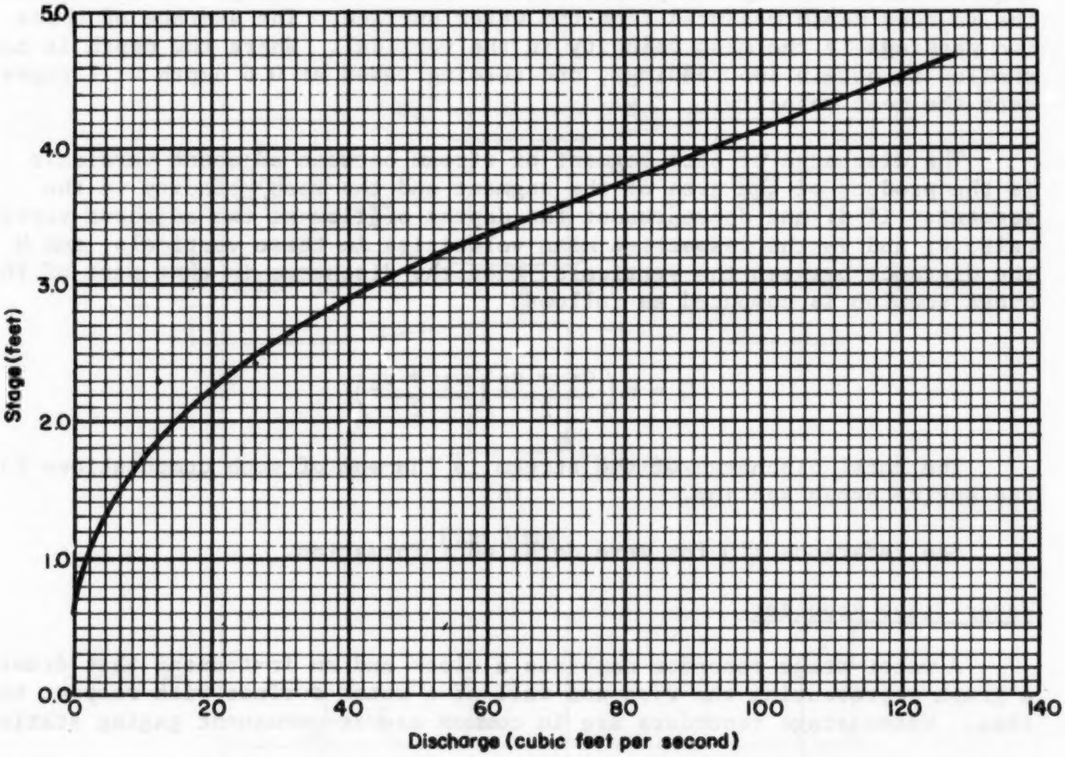


Figure 3-26 Stage-discharge curve for unlined irrigation canals

Measurements by Floats

The velocity of a canal or stream, and hence its discharge, may be determined approximately by the use of surface floats and channel cross sections.

A stretch of the canal, straight and uniform in cross section and grade, with a minimum of surface waves, should be chosen for this method. Surface velocity measurements should be made on a windless day, for even under the best conditions the floats often are diverted from a direct course between measuring stations.

The width of the canal should be divided into segments, and the average depth determined for each segment. The segments should be narrower in the outer thirds of the canal than in the central third. Float courses should be laid out in the middle of the strips defined by the segments. For regular-shaped channels flowing in a straight course under favorable conditions, the mean velocity of a strip in the channel is approximately 0.85 times its surface velocity. This value is an average of many observations. For any particular channel it may be as low as 0.80 or as high as 0.95.

The velocity of the float in each strip, after being adjusted to mean velocity, multiplied by the cross-sectional area of the strip, will give the discharge. The sum of the discharges of the strips is the total discharge. On small streams, rather than dividing the stream into segments a number of float runs can be made and an average of these used for the surface velocity of the stream. The float method is an approximate method and should be used only with its limitations in mind.

Slope-Area Method

The slope-area method consists of using the slope of the water surface in a uniform reach of channel, and the average cross-sectional area of that reach, to give a rate of discharge. The discharge may be computed from Manning's Equation 3-16:

$$Q = \frac{1.486}{n} ar^{2/3}s^{1/2}$$

A straight course of the channel should be chosen, at least 200 feet and preferably 1,000 feet in length. The course should be free of rapids, abrupt falls, sudden contractions, or expansions.

The slope of the water surface may be calculated by dividing the difference in the water surface elevations at the two ends of the course by the length of the course. If it is desired to develop a stage-discharge curve for the channel, gage points, carefully referenced to a common datum level, should be placed one on each bank of the channel and one in the center of the stream, in stilling-wells if possible.

In irregular channels, the area and the wetted perimeter at several cross sections is required and a mean value should be used in computing hydraulic radius.

Inasmuch as the proper selection of the roughness factor n for many streams is difficult, the discharge determined by the slope-area method is only approximate. Care must be taken to determine the slope and areas simultaneously when the water levels are changing. Various hydraulic textbooks and handbooks provide tables to assist in the computation of discharges from the above field data.

Velocity-Head Rod

The velocity-head rod is a simple inexpensive rod that can be used to measure the approximate velocity in open channels, if depths and velocities are not too great. This infrequently-used method is discussed in detail in Chapter 9, Section 15, SCS National Engineering Handbook.

PIPE FLOW

The following methods may be used in determining pipe flow:

Orifice Flow

Pipe orifices, Figure 3-27, usually are circular orifices placed in or at the end of a horizontal pipe. The head on the orifice is measured with a manometer.

Where the orifice is placed in the pipe, the discharge will not be free and the head must be measured at points both upstream and downstream from the orifice. For a further discussion of this type of orifice, refer to King's Handbook of Hydraulics.

The pipe orifice commonly used in measuring irrigation water and the discharge from wells within a range of 50 to 2,000 gallons per minute has the circular orifice located at the end of the pipe.

The pipe must be level. A glass-tube manometer is placed about 24 inches upstream from the orifice. No elbows, valves, or other fittings should be closer than 4 feet upstream from the manometer. The ratio of the orifice diameter to the pipe diameter should be no less than 0.50 nor greater than 0.83. The ratio to be selected, however, must cause the pipe to flow full. The head in the manometer is measured with an ordinary carpenter's rule.

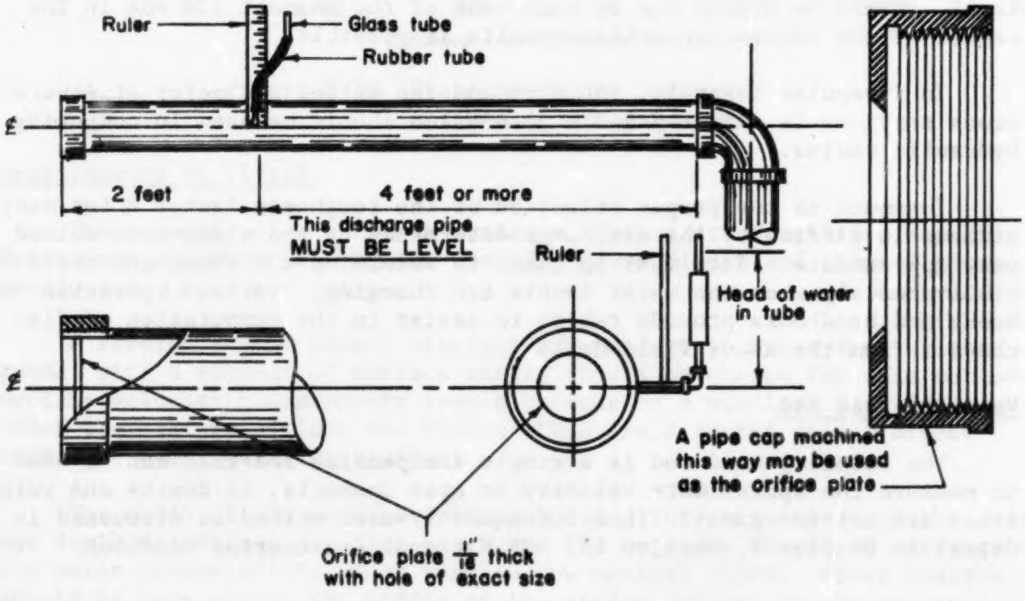

Ruler
Glass tube
Rubber tube
℄
2 feet
4 feet or more
This discharge pipe
MUST BE LEVEL
Ruler
Head of water in tube
℄
A pipe cap machined this way may be used as the orifice plate
Orifice plate $\frac{1}{16}$" thick with hole of exact size

Figure 3-27 Pipe orifice

Discharge through the orifice is computed by Equation 3-25, or it can be read directly from Exhibit 3-18.

$$Q = Ca\sqrt{2gh}$$

where:

Q = orifice discharge in gallons per minute
C = coefficient which varies with the ratio of the orifice diameter to the pipe diameter as well as with all the other factors affecting flow in orifices. The value of the coefficient (C) may be taken from Figure 3-28
a = cross-sectional area of the orifice in square inches
g = acceleration due to gravity - 32.2 feet per second per second
h = head on the orifice in inches measured above its center

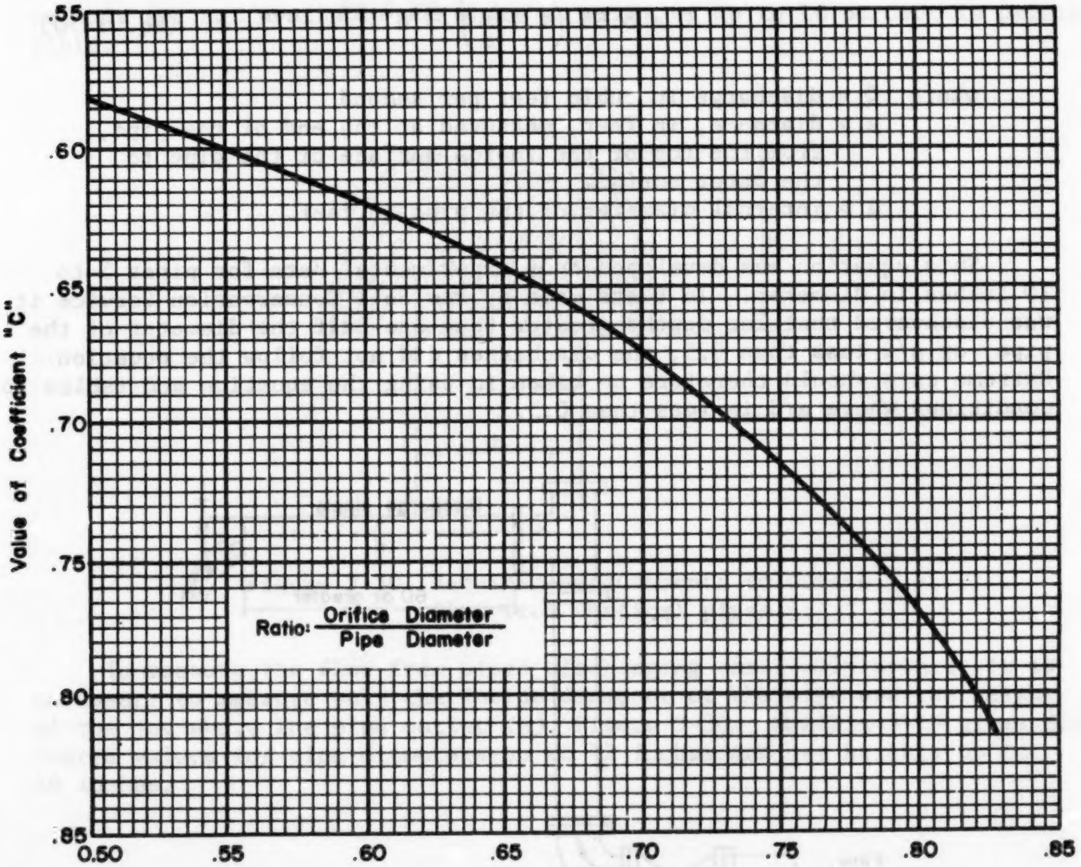


Figure 3-28 Orifice coefficients

California Pipe Method

B. R. Vanleer developed a method for measuring the discharge from the open end of a partially-filled horizontal pipe discharging freely into the air. This method can also be adapted to the measurement of discharge in small open channels where such flow can be diverted through a horizontal pipe flowing partially full and discharging freely into the air.

The method has four requirements for accurate results: 1) The discharge pipe must be level; 2) it must discharge partially full; 3) it must discharge freely into air; and 4) the velocity of approach must be a minimum. Figure 3-29 illustrates one method of meeting these requirements. Other designs may be possible. With such an arrangement, the only measurements necessary are the inside diameter of the pipe and the vertical distance from the upper inside surface of the pipe to the surface of the flowing water at the outlet end of the pipe. The discharge may then be computed by the equation:

$$Q = 8.69 \left(1 - \frac{a}{d}\right)^{1.88} d^{2.48} \qquad \text{(Eq. 3-30)}$$

where Q = discharge in cubic feet per second
a = distance, in feet, measured at the end of the pipe, from the top of the inside surface of the pipe to the water surface
d = internal diameter of the pipe in feet.

This equation was developed from experimental data for pipes 3 to 10 inches in diameter. In tests made by the Soil Conservation Service it was discovered that for depths greater than one-half the diameter of the pipe, or a/d less than 0.5, the discharges did not follow the equation. Extreme care should therefore be taken in using the equation and tables for conditions where a/d is less than 0.5.

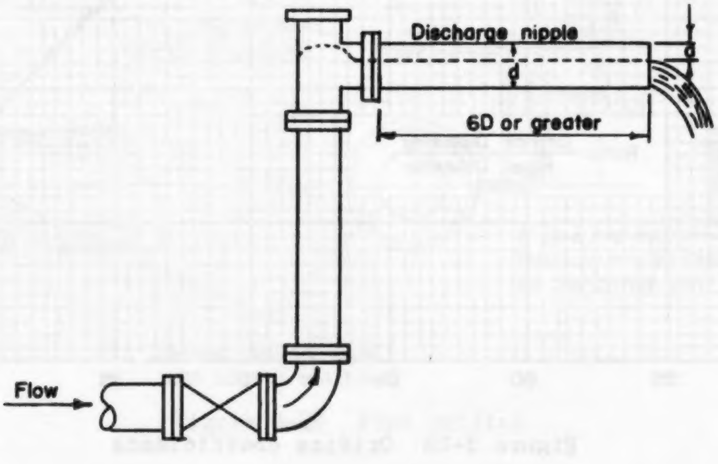


Figure 3-29 Measuring flow by the California pipe method

Tables 48 and 49 in the Water Measurement Manual, Bureau of Reclamation, provide assistance for solving the equation for discharge.

Coordinate Method

In this method, coordinates of the jet issuing from the end of a pipe are measured. The flow from pipes may be measured whether the pipe is discharging vertically upward, horizontally, or at some angle with the horizontal. Since the discharge pipe can be set in a horizontal position for measurement purposes, there is no need here for a discussion of flow from pipe in an angular position.

Coordinate methods are used to measure the flow from flowing wells (discharging vertically) and from small pumping plants (discharging horizontally). These methods have limited accuracy owing to the difficulty in making accurate measurements of the coordinates of the jet. They should be used only where facilities for making more accurate measurements by other methods are not available and where an error of up to 10 percent is permissible.

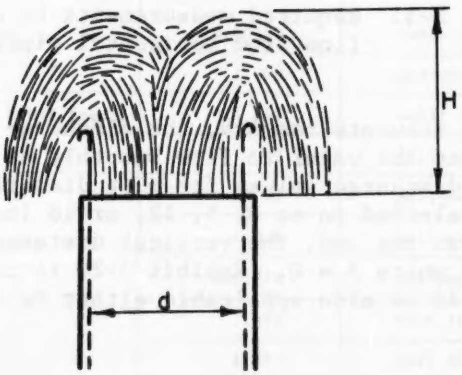


Figure 3-30 Required measurements to obtain flow from vertical pipes

To measure the flow from pipes discharging vertically upward, it is necessary to measure only the inside diameter of the pipe and the height of the jet above the pipe outlet (H), Figure 3-30. Exhibit 3-19 gives discharge values for pipe diameters up to 12 inches and jet heights up to 40 inches.

To measure the flow from pipes discharging horizontally, it is necessary to measure both a horizontal and a vertical distance from the top of the inside of the pipe to a point on the top of the jet. See Figure 3-31. These horizontal and vertical distances are called X and Y ordinates, respectively.

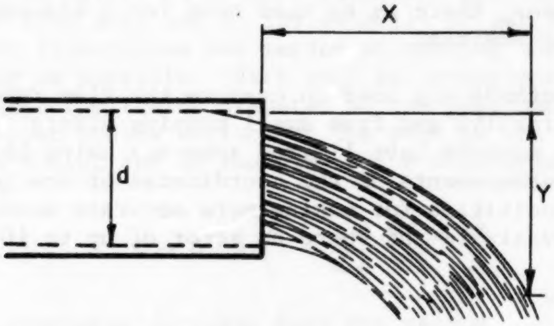


Figure 3-31 Required measurements to obtain flow from horizontal pipes

For reasonably accurate results, the discharge pipe must be level and long enough to permit the water to flow smoothly as it issues from the pipe. Exhibit 3-20 gives discharge values for pipe diameters up to 6 inches where the ordinate X is selected to be 0, 6, 12, or 18 inches. For pipes flowing less than 0.8 full at the end, the vertical distance Y can be measured at the end of the pipe where X = 0. Exhibit 3-20 is used to obtain the discharge. Exhibit 3-20 is also applicable either to conditions of full flow or partial flow.

THIS	TIMES THIS	GIVES YOU THIS
VOLUME		
1 gallon (gal)	231	cubic inches (cu in.)
	.1337	cubic feet (cu ft)
1 million gallon (mg)	3.0689	acre feet (acre-ft)
1 cubic foot	1,728	cubic inches
	7.48	gallons
1 acre foot (amount of water required to cover one acre one foot deep)	43,560	cubic feet
	325,850	gallons
	12	acre inches
WEIGHT		
1 gallon	8.33	pounds (lb)
1 cubic foot	62.4	pounds
FLOW		
1 gallon per minute (gpm)	0.00223	cubic feet per second (cfs)
	1,440	gallons per day (24 hours)
1 million gallon per 24 hours (mgd)	1.547	cubic feet per second
	695	gallons per minute
1 cubic foot per second	7.48	gallons per second (gps)
	448.8	gallons per minute
	646,272	gallons per day (24 hours)
	.992	acre inch per hour
	1.983	acre feet per day (24 hours)
	40	miner's inches (legal value 1/)
	50	miner's inches (legal value 2/)
	38.4	miner's inches (in Colorado)
	35.7	miner's inches (in British Columbia)
1 miner's inch	11.25	gpm when equivalent to 1/40 second foot
	9	gpm when equivalent to 1/50 second foot

1/ In Arizona, California, Montana, Nevada and Oregon

2/ In Idaho, Kansas, Nebraska, New Mexico, North Dakota, South Dakota, and Utah

Exhibit 3-1 Water volume, weight and flow equivalents

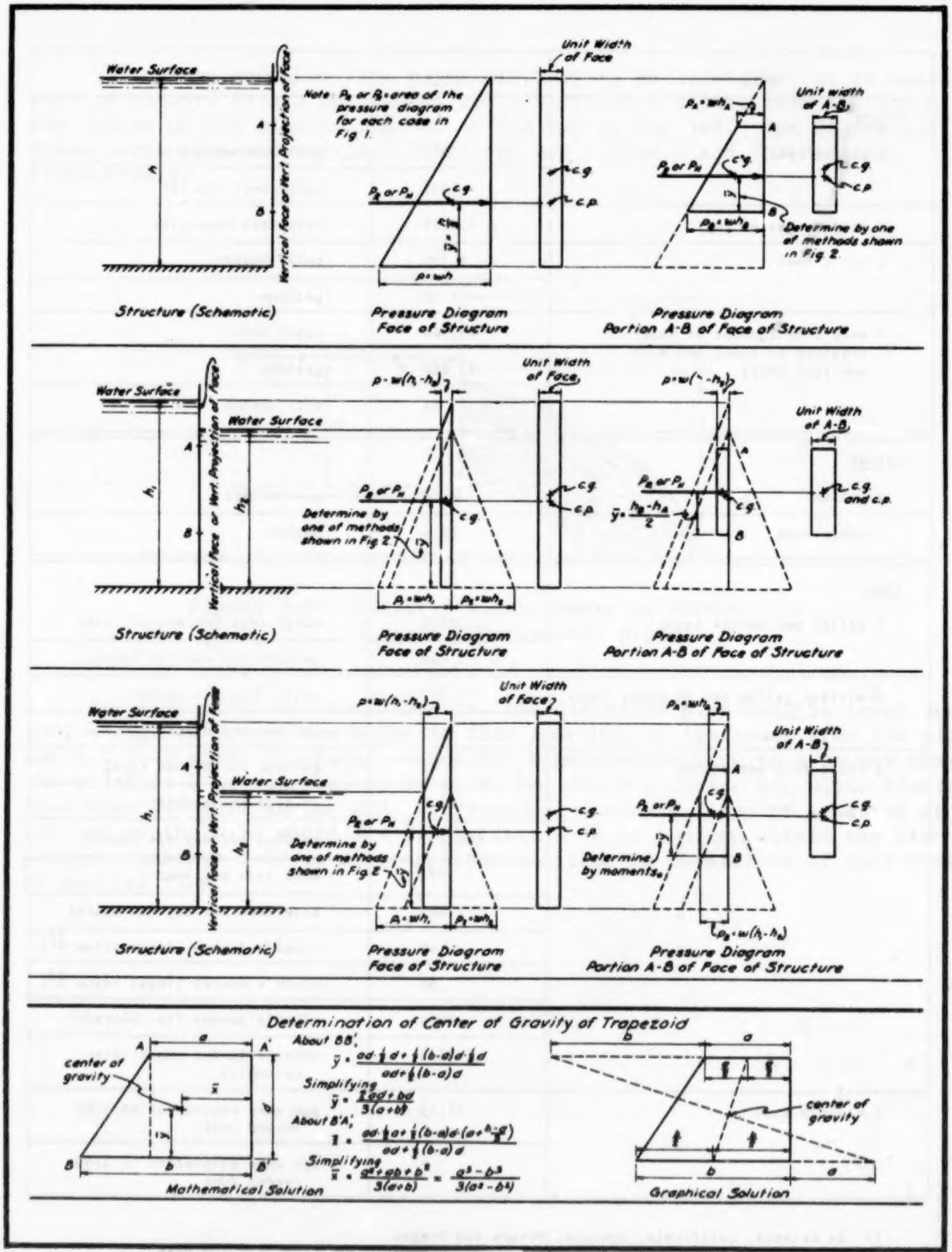
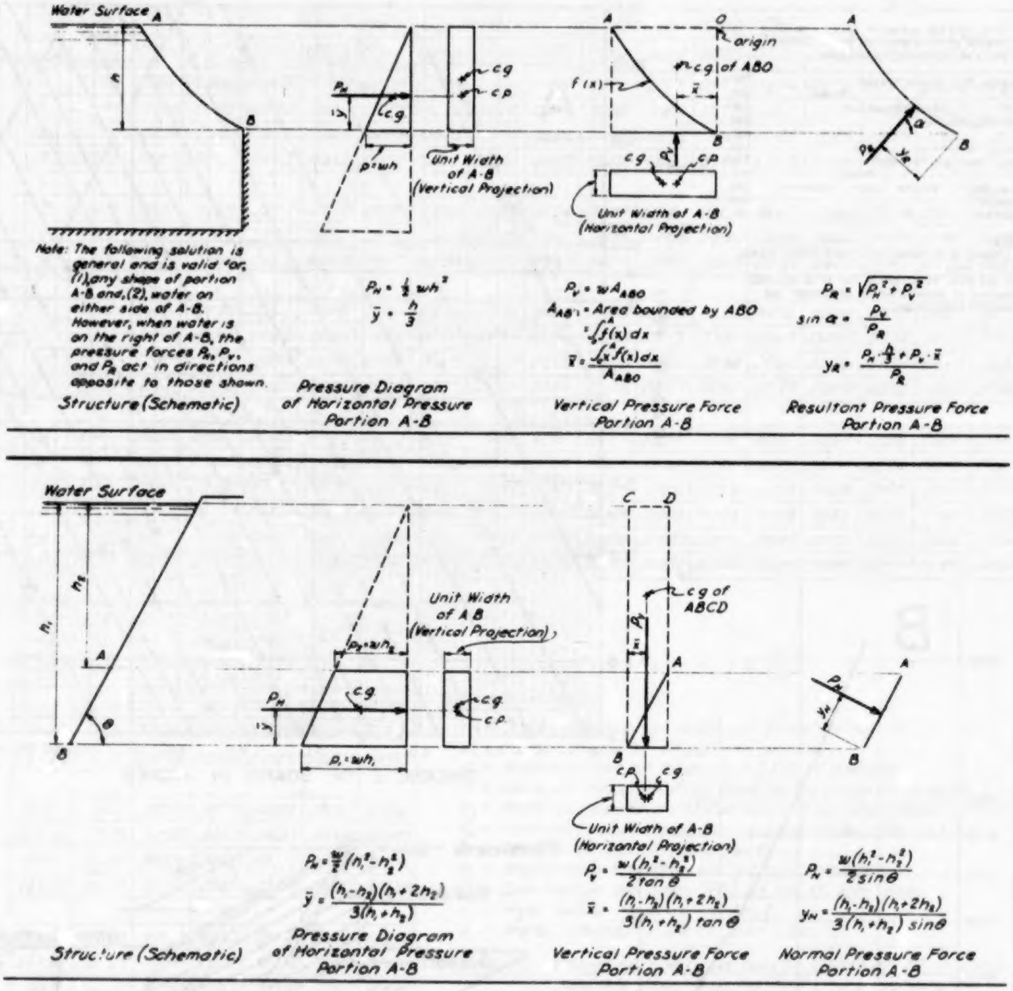

Water Surface
Vertical Face or Vert. Projection of Face
Note: P_R or P_H = area of the pressure diagram for each case in Fig 1.
Unit Width of Face
P_R or P_H
c.g.
c.p.
$p = wh$
$p_A = wh_A$
$p_B = wh_B$
Unit width of A-B
Determine by one of methods shown in Fig 2.
Structure (Schematic)
Pressure Diagram Face of Structure
Pressure Diagram Portion A-B of Face of Structure
$p = w(h_1 - h_2)$
$p_1 = wh_1$
$p_2 = wh_2$
c.g. and c.p.
$\bar{y} = \frac{h_2 - h_A}{2}$
Determine by moments
$p_B = w(h_1 - h_2)$
Determination of Center of Gravity of Trapezoid
About BB';
$\bar{y} = \frac{ad \cdot \frac{1}{2}d + \frac{1}{2}(b-a)d \cdot \frac{1}{3}d}{ad + \frac{1}{2}(b-a)d}$
Simplifying
$\bar{y} = \frac{2ad + bd}{3(a+b)}$
About B'A';
$\bar{x} = \frac{ad \cdot \frac{1}{2}a + \frac{1}{2}(b-a)d \cdot (a + \frac{b-a}{3})}{ad + \frac{1}{2}(b-a)d}$
Simplifying
$\bar{x} = \frac{a^2 + ab + b^2}{3(a+b)} = \frac{a^3 - b^3}{3(a^2 - b^2)}$
center of gravity
Mathematical Solution
Graphical Solution

Exhibit 3-2 Pressure diagrams and methods of computing hydrostatic loads (Ref. NEH Section 5, ES-31)
(Sheet 1 of 2)


Water Surface
A
h
B
P_H
cg
cp
$\frac{h}{3}$
$p = wh$
Unit Width of A-B (Vertical Projection)
O
origin
cg of ABO
f (x)
$\bar{x}$
α
Unit Width of A-B (Horizontal Projection)
P_V
P_R
y_R
90°
Note: The following solution is general and is valid for, (1) any shape of portion A-B and, (2), water on either side of A-B. However, when water is on the right of A-B, the pressure forces P_H, P_V, and P_R act in directions opposite to those shown.
$P_H = \frac{1}{2} wh^2$
$\bar{y} = \frac{h}{3}$
$P_V = wA_{ABO}$
A_{ABO} = Area bounded by ABO
$= \int_O^A f(x)\,dx$
$\bar{x} = \frac{\int_O^A x f(x)\,dx}{A_{ABO}}$
$P_R = \sqrt{P_H^2 + P_V^2}$
$\sin\alpha = \frac{P_V}{P_R}$
$y_R = \frac{P_H \cdot \frac{h}{3} + P_V \cdot \bar{x}}{P_R}$
Structure (Schematic)
Pressure Diagram of Horizontal Pressure Portion A-B
Vertical Pressure Force Portion A-B
Resultant Pressure Force Portion A-B
Water Surface
h_2
h_1
A
B
θ
$p_2 = wh_2$
P_H
c.g.
c.p.
$p_1 = wh_1$
Unit Width of A B (Vertical Projection)
C
D
cg of ABCD
P_V
$\bar{x}$
A
B
cp
cg
Unit Width of A-B (Horizontal Projection)
P_N
y_N
A
B
$P_H = \frac{w}{2}(h_1^2 - h_2^2)$
$\bar{y} = \frac{(h_1 - h_2)(h_1 + 2h_2)}{3(h_1 + h_2)}$
$P_V = \frac{w(h_1^2 - h_2^2)}{2\tan\theta}$
$\bar{x} = \frac{(h_1 - h_2)(h_1 + 2h_2)}{3(h_1 + h_2)\tan\theta}$
$P_N = \frac{w(h_1^2 - h_2^2)}{2\sin\theta}$
$y_N = \frac{(h_1 - h_2)(h_1 + 2h_2)}{3(h_1 + h_2)\sin\theta}$
Structure (Schematic)
Pressure Diagram of Horizontal Pressure Portion A-B
Vertical Pressure Force Portion A-B
Normal Pressure Force Portion A-B

Symbols and Definitions

c.g.	center of gravity of area, as indicated.
c.p.	center of pressure; i.e., point of action of a pressure force, or a component of a pressure force, on the face, or a projection of the face, of a structure.
h	height of water above a point, as indicated in "Structure (Schematic)", or as indicated by subscript.
p	intensity of pressure at a point indicated by subscript, or at bottom of structure or portion of structure if no subscript is used.
P_H	horizontal component of pressure force per foot width.
P_V	vertical component of pressure force per foot width.
P_N	normal pressure force per foot width.
P_R	resultant pressure force per foot width.
w	weight of water per cubic foot.
$\bar{x}, \bar{y}$	coordinates of c.g. of pressure diagram.
y_N	distance from given point perpendicular to line of action of P_N.
y_R	distance from given point perpendicular to line of action of P_R.

Exhibit 3-2 Pressure diagrams and methods of computing hydrostatic loads (Ref. NEH Section 5, ES-31)

(Sheet 2 of 2)

Unit Working Stresses (psi) - Bending
Common or Construction Grade Timber
Wet and Weathered Conditions

Douglas Fir, Coast Region	750
" " " " , Dense	880
" " , Rocky Mountain	530
Hemlock, Western	680
" "	600
Larch, Western	680
Pine, Southern Yellow	750
" " " , Dense	880
Pine, White, Yellow, Sugar, Ponderosa	570
Redwood	600
Tamarack	680

NOTES:
(1) Chart A is based on a unit fiber stress of 1000 psi.
(2) See Std. Drwg. ES-26 for unit working stresses of other species of timber and moisture conditions.

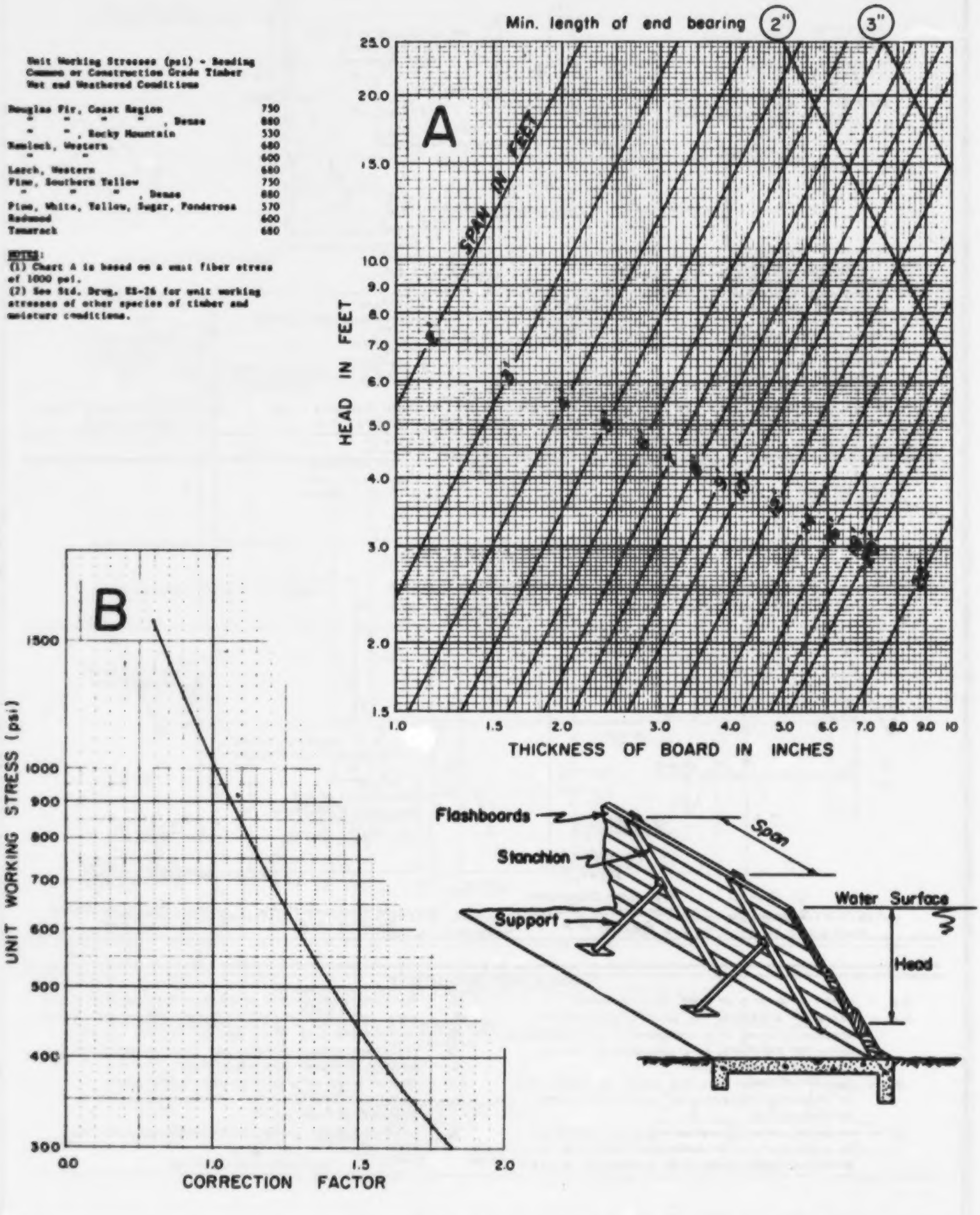


Exhibit 3-3 Required thickness of flashboards (ref. Western States Engineering Handbook Section 6)

HEAD LOSS COEFFICIENT, K_p, FOR CIRCULAR PIPE FLOWING FULL $K_p = \frac{5087\, n^2}{d_i^{16/3}}$

Pipe diam. inches	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n"															
		0.010	0.011	0.012	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025
6	0.196	0.0467	0.0565	0.0672	0.0789	0.0914	0.1050	0.1194	0.1348	0.151	0.168	0.187	0.206	0.226	0.247	0.269	0.292
8	0.349	.0318	.0385	.0458	.0537	.0623	.0715	.0814	.0919	.1030	.1148	.1272	.140	.154	.168	.183	.199
10	0.545	.0236	.0286	.0340	.0399	.0463	.0531	.0604	.0682	.0765	.0852	.0944	.1041	.1143	.1249	.136	.148
12	0.785	.0185	.0224	.0267	.0313	.0363	.0417	.0474	.0535	.0600	.0668	.0741	.0817	.0896	.0980	.1067	.1157
14	1.069	.0151	.0182	.0217	.0255	.0295	.0339	.0386	.0436	.0488	.0544	.0603	.0665	.0730	.0798	.0868	.0942
15	1.23	.0138	.0166	.0198	.0232	.0270	.0309	.0352	.0397	.0446	.0496	.0550	.0606	.0666	.0727	.0792	.0859
16	1.40	.0126	.0153	.0182	.0213	.0247	.0284	.0323	.0365	.0409	.0455	.0505	.0556	.0611	.0667	.0727	.0789
18	1.77	.01078	.0130	.0155	.0182	.0211	.0243	.0276	.0312	.0349	.0389	.0431	.0476	.0522	.0570	.0621	.0676
21	2.41	.00878	.01062	.0126	.0148	.0172	.0198	.0225	.0254	.0284	.0317	.0351	.0387	.0425	.0464	.0506	.0549
24	3.14	.00735	.00889	.01058	.0124	.0144	.0165	.0188	.0212	.0238	.0265	.0294	.0324	.0356	.0389	.0423	.0459
27	3.98	.00628	.00760	.00904	.01061	.0123	.0141	.0161	.0181	.0203	.0227	.0251	.0277	.0304	.0332	.0362	.0393
30	4.91	.00546	.00660	.00786	.00922	.01070	.01228	.0140	.0158	.0177	.0197	.0218	.0241	.0264	.0289	.0314	.0341
36	7.07	.00428	.00518	.00616	.00723	.00839	.00963	.01096	.0124	.0139	.0154	.0171	.0189	.0207	.0226	.0246	.0267
42	9.62	.00348	.00422	.00502	.00589	.00683	.00784	.00892	.01007	.01129	.0126	.0139	.0154	.0169	.0184	.0201	.0218
48	12.57	.00292	.00353	.00420	.00493	.00572	.00656	.00747	.00843	.00945	.01053	.01166	.0129	.0141	.0154	.0168	.0182
54	15.90	.00249	.00302	.00359	.00421	.00488	.00561	.00638	.00720	.00808	.00900	.00997	.01099	.0121	.0132	.0144	.0156
60	19.63	.00217	.00262	.00312	.00366	.00426	.00487	.00554	.00626	.00702	.00782	.00866	.00955	.01048	.0115	.0125	.0135

HEAD LOSS COEFFICIENT, K_c, FOR SQUARE CONDUIT FLOWING FULL $K_c = \frac{29.16\, n^2}{r^{4/3}}$

Conduit Size feet	Flow area sq. ft.	MANNING'S COEFFICIENT OF ROUGHNESS "n"				
		0.012	0.013	0.014	0.015	0.016
2×2	4.00	0.01058	0.01242	0.01440	0.01653	0.01880
2½×2½	6.25	0.00786	0.00922	0.01070	0.01228	0.01397
3×3	9.00	.00616	.00723	.00839	.00963	.01096
3½×3½	12.25	.00502	.00589	.00683	.00784	.00892
4×4	16.00	.00420	.00495	.00572	.00656	.00746
4½×4½	20.25	.00359	.00421	.00488	.00561	.00638
5×5	25.00	.00312	.00366	.00425	.00487	.00554
5½×5½	30.25	.00275	.00322	.00374	.00429	.00488
6×6	36.00	.00245	.00287	.00333	.00382	.00435
6½×6½	42.25	.00220	.00258	.00299	.00343	.00391
7×7	49.00	.00199	.00234	.00271	.00311	.00354
7½×7½	56.25	.00182	.00213	.00247	.00284	.00323
8×8	64.00	.00167	.00196	.00227	.00260	.00296
8½×8½	72.25	.00154	.00180	.00209	.00240	.00273
9×9	81.00	.00142	.00167	.00194	.00223	.00253
9½×9½	90.25	.00133	.00156	.00180	.00207	.00236
10×10	100.00	.00124	.00145	.00168	.00193	.00220

$$H_1 = (K_p \text{ or } K_c)\, L\, \frac{v^2}{2g}$$

Nomenclature:

a = Cross-sectional area of flow in sq. ft.
d_i = Inside diameter of pipe in inches.
g = Acceleration of gravity = 32.2 ft. per sec.
H_1 = Loss of head in feet due to friction in length L.
K_c = Head loss coefficient for square conduit flowing full.
K_p = Head loss coefficient for circular pipe flowing full.
L = Length of conduit in feet.
n = Manning's coefficient of roughness.
Q = Discharge or capacity in cu. ft. per sec.
r = Hydraulic radius in feet.
v = Mean velocity in ft. per sec.

Example 1: Compute the head loss in 300 ft. of 24 in. diam. concrete pipe flowing full and discharging 30 c.f.s. Assume $n = 0.015$

$$v = \frac{Q}{a} = \frac{30}{3.14} = 9.55 \text{ f.p.s.}; \quad \frac{v^2}{2g} = \frac{(9.55)^2}{64.4} = 1.42 \text{ ft.}$$

$$H_1 = K_p L \frac{v^2}{2g} = 0.0165 \times 300 \times 1.42 = 7.03 \text{ ft.}$$

Example 2: Compute the discharge of a 250 ft., 3×3 square conduit flowing full if the loss of head is determined to be 2.25 ft. Assume $n = 0.014$.

$$H_1 = K_c L \frac{v^2}{2g}; \quad \frac{v^2}{2g} = \frac{H_1}{K_c L} = \frac{2.25}{0.00839 \times 250} = 1.073 \text{ ft.}$$

$$v = \sqrt{64.4 \times 1.073} = 8.31; \quad Q = 9 \times 8.31 = 74.8 \text{ c f s.}$$

Exhibit 3-4 Head loss coefficients for circular and square conduits flowing full (Ref. NEH Section 5, ES-42)

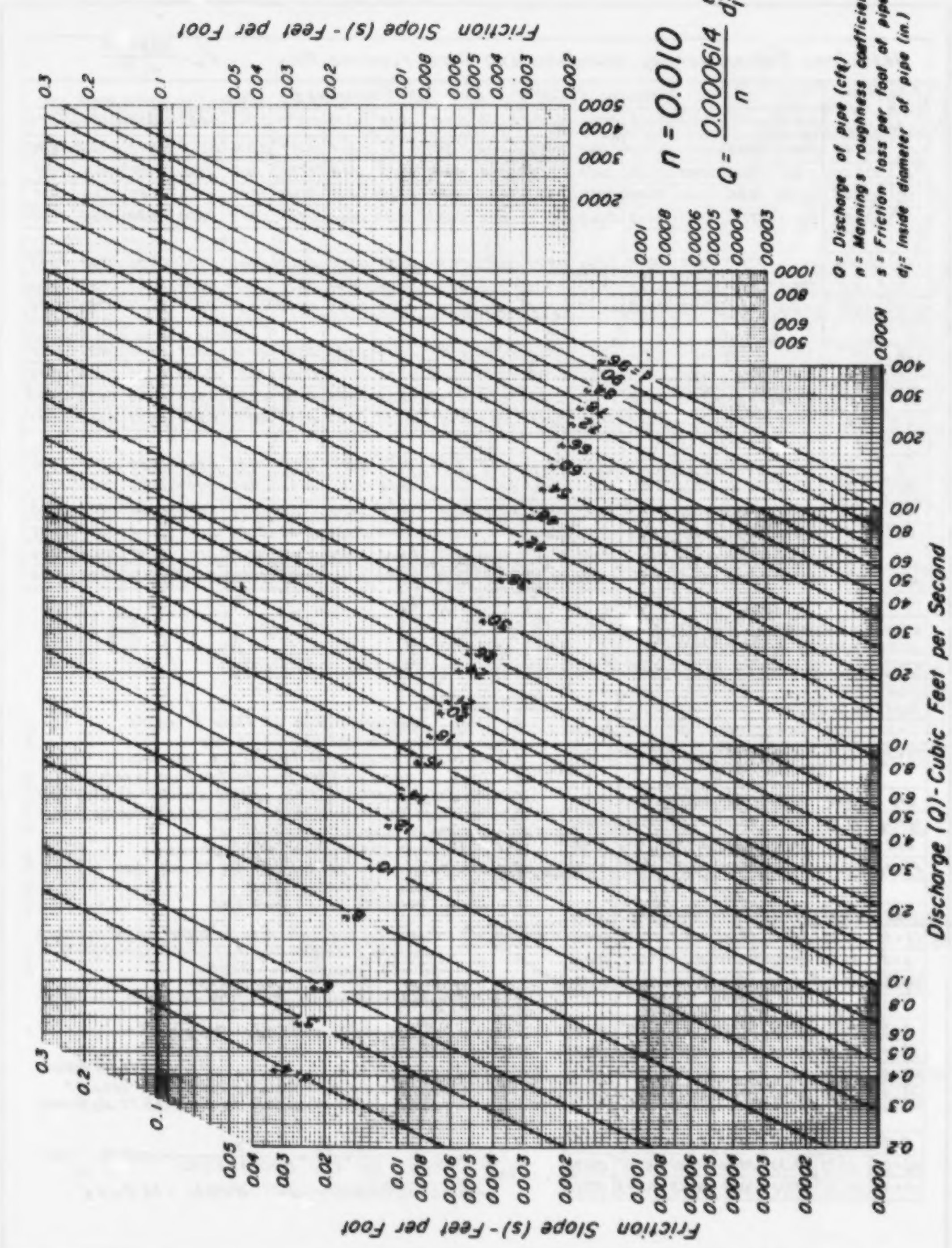


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.010 (Sheet 1 of 6)

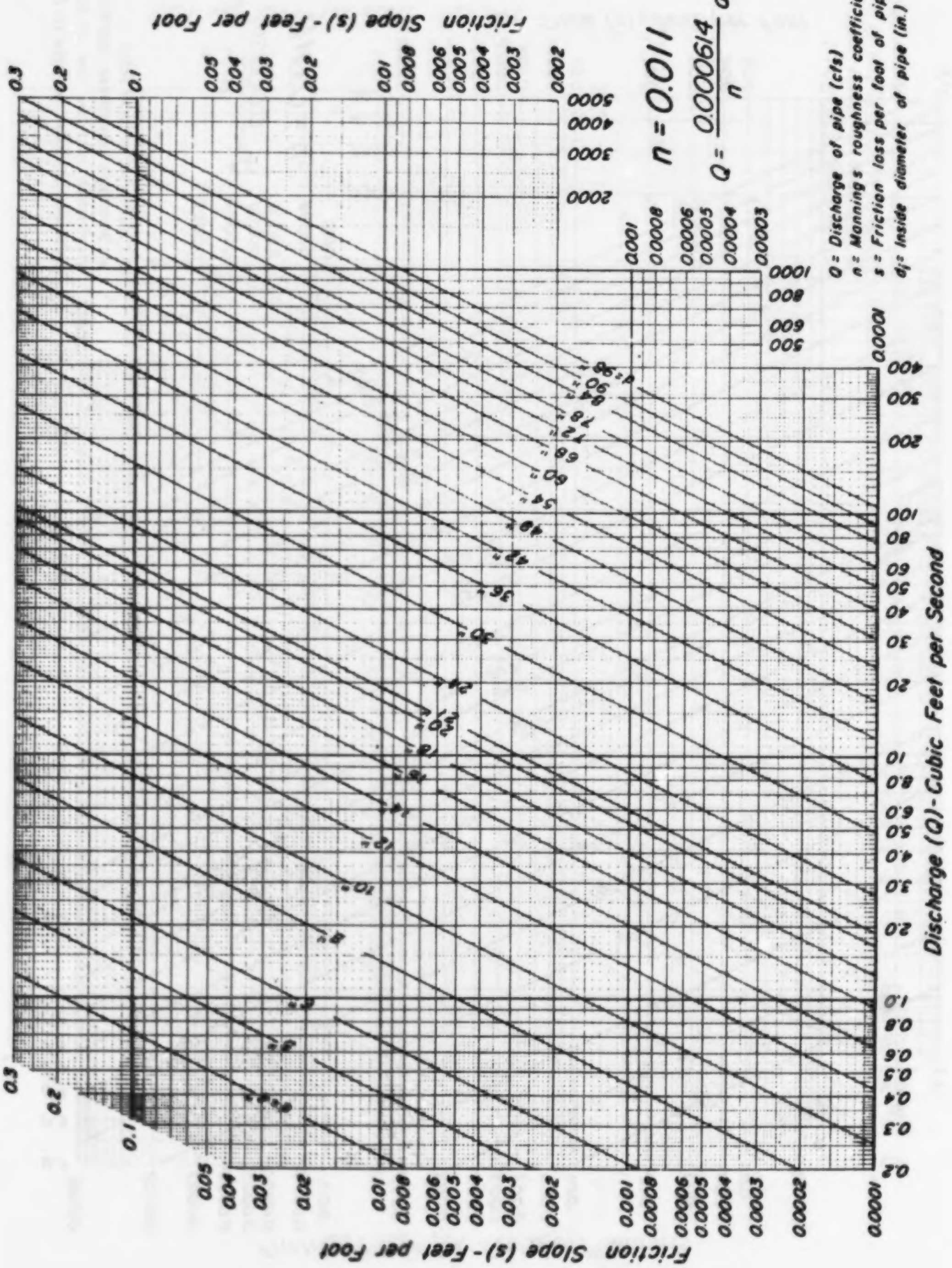


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.011 (Ref. NEH Section 5, ES-54)
(Sheet 2 of 6)

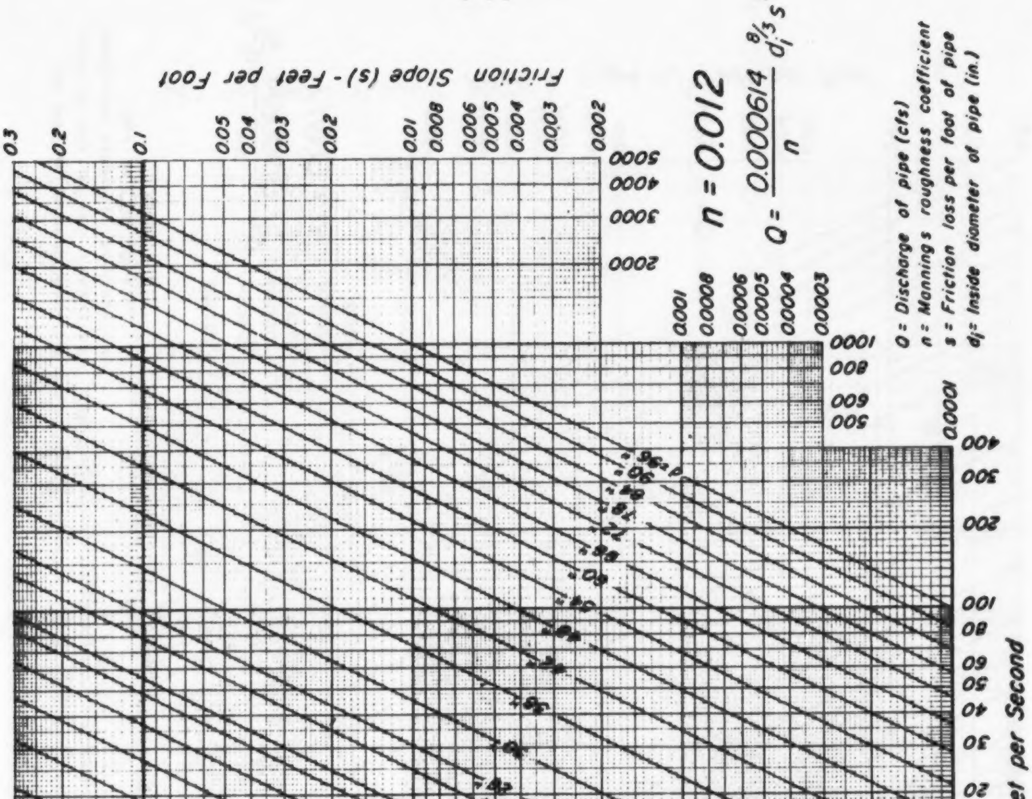


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.012 (Sheet 3 of 6)

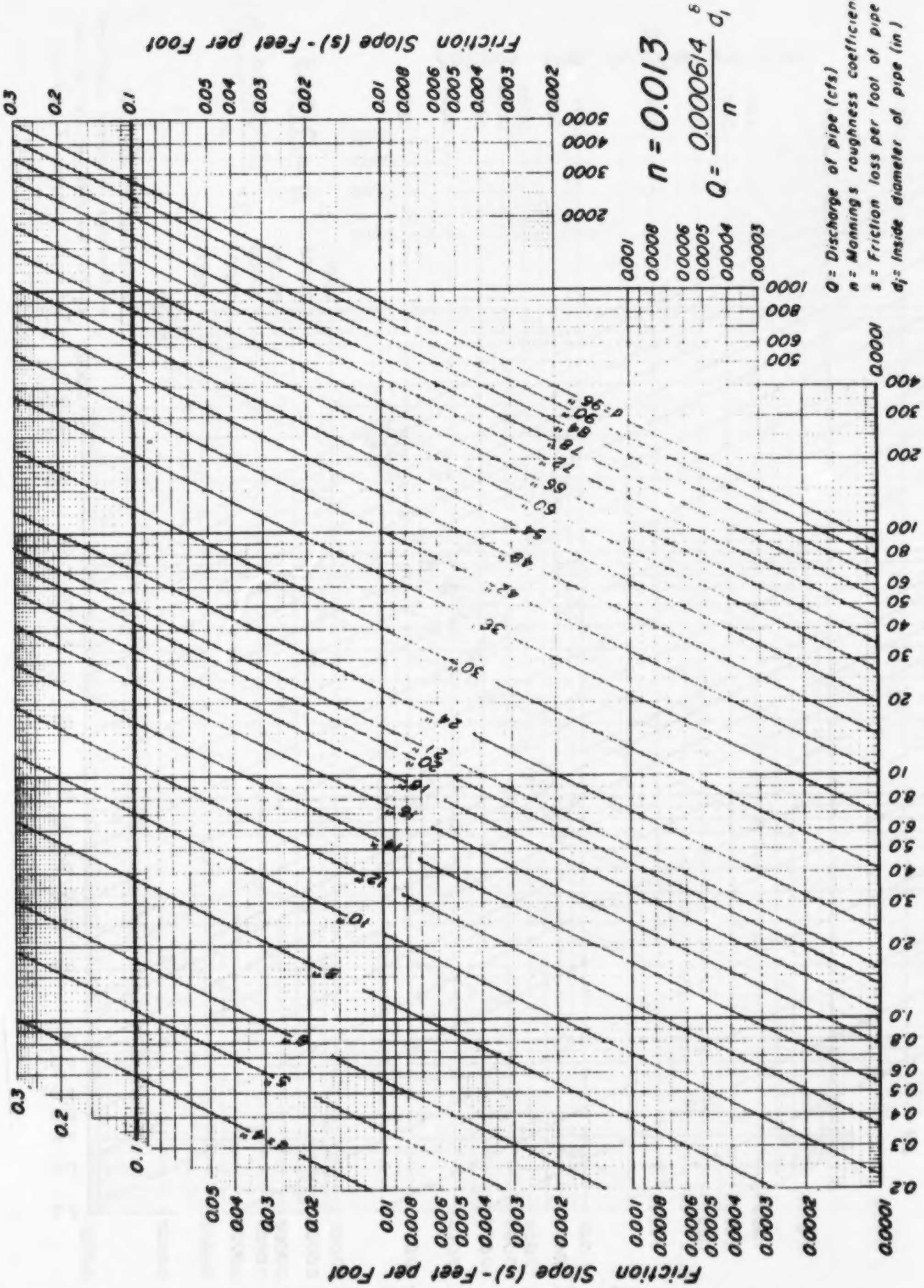


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.013 (Ref. NEH Section 5, ES-54) (Sheet 4 of 6)

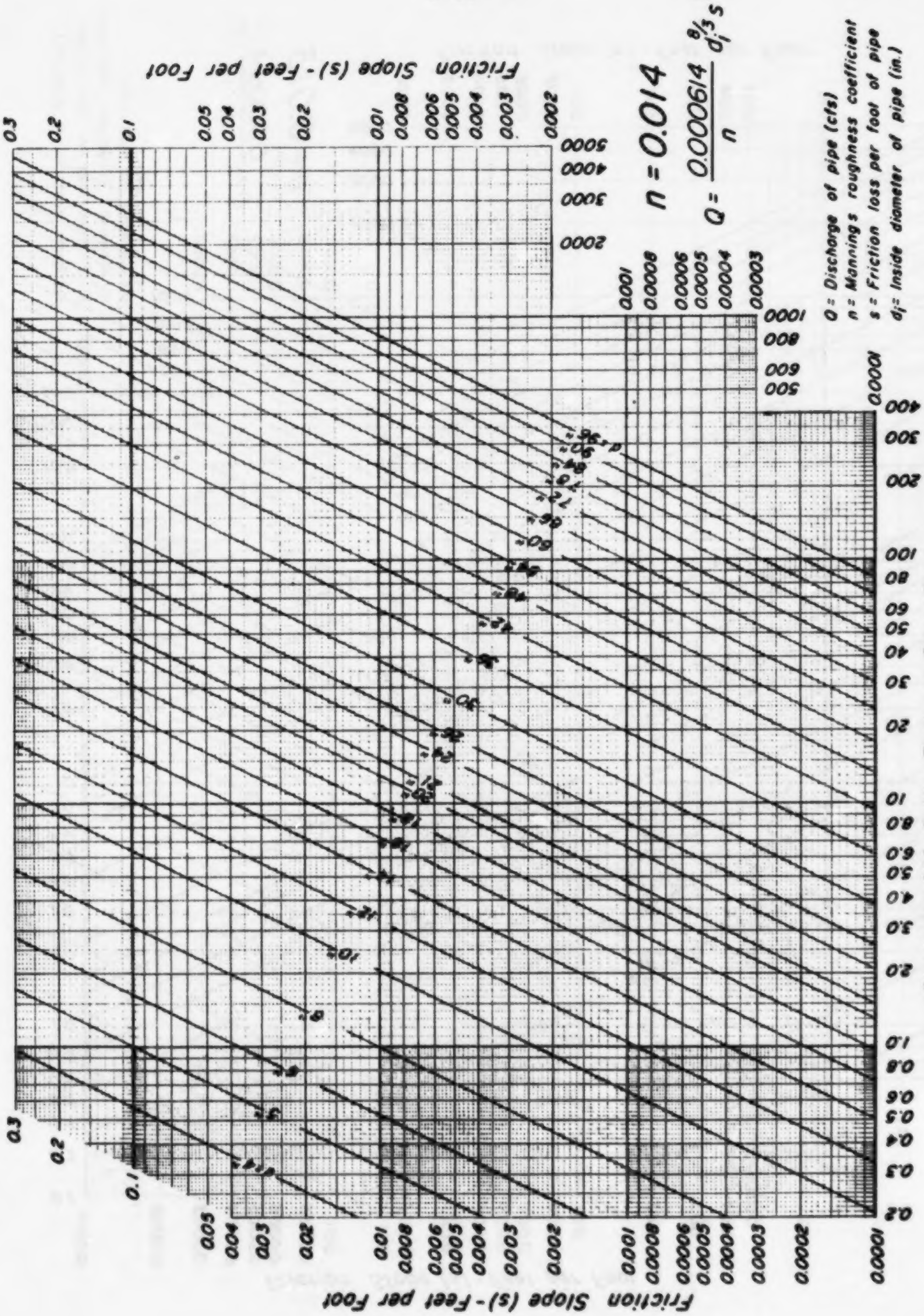


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.014 (Sheet 5 of 6)

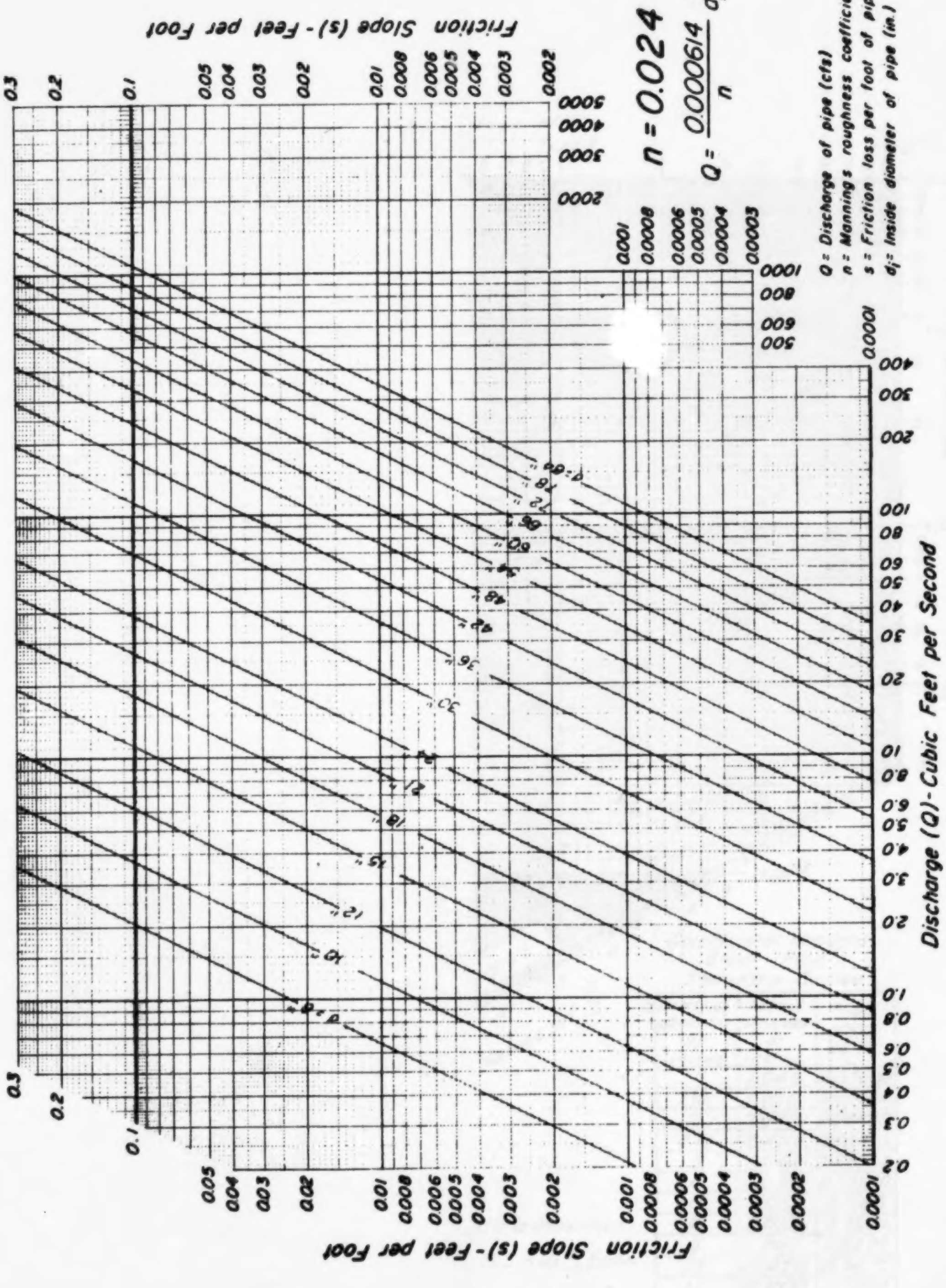
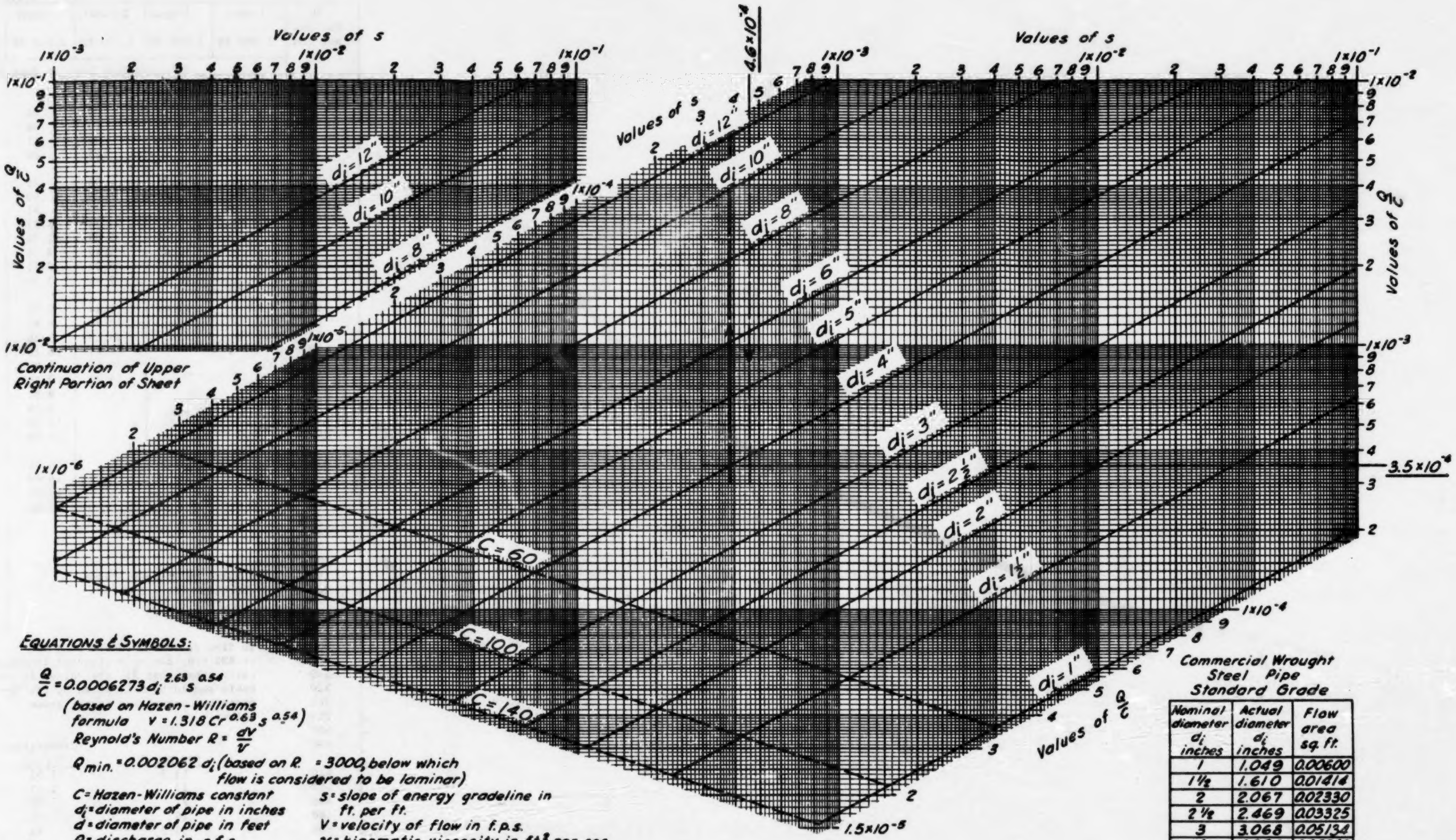


Exhibit 3-5 Discharge of circular pipes flowing full.
Manning's n = 0.024 (Sheet 6 of 6)



EQUATIONS & SYMBOLS:

$\frac{Q}{C} = 0.0006273\, d_i^{2.63} s^{0.54}$

(based on Hazen-Williams formula $V = 1.318\, C r^{0.63} s^{0.54}$)

Reynold's Number $R = \frac{dV}{\nu}$

$Q_{min.} = 0.002062\, d_i$ (based on $R = 3000$, below which flow is considered to be laminar)

C = Hazen-Williams constant

d_i = diameter of pipe in inches

d = diameter of pipe in feet

Q = discharge in c.f.s.

r = hydraulic radius in feet

s = slope of energy gradeline in ft. per ft.

V = velocity of flow in f.p.s.

ν = kinematic viscosity in ft.² per sec. (assumed to be 1.05×10^{-5} ft.² per sec. for water at 70°F.)

Note: Dashed lines pass through minimum values of Q/C for the given C. For lesser values of Q/C, according to the assumptions of ν and R, there can be no assurance of turbulent flow.

Example: Find size pipe required to carry Q = 0.042 cfs with a maximum energy gradient S = 0.00046 if C = 120. Then $Q/C = \frac{0.042}{120} = 3.5 \times 10^{-4}$. Enter chart, with above values, and find d_i = 4 in.. Actual head loss in 4 in. pipe = 3.85×10^{-4} ft. per ft.

Commercial Wrought Steel Pipe Standard Grade

Nominal diameter d_i inches	Actual diameter d_i inches	Flow area sq. ft.
1	1.049	0.00600
1½	1.610	0.01414
2	2.067	0.02330
2½	2.469	0.03325
3	3.068	0.05134
4	4.026	0.08840
5	5.047	0.1389
6	6.065	0.2006
8	7.981	0.3474
10	10.020	0.5475
12	12.000	0.7854

Exhibit 3-6 Solution of Hazen-Williams formula for round pipes (Ref. NEH Section 5, ES-40)

For IPS Pipe

Q Gallons per min.	1-inch 1.189 ID	1¼-inch 1.502 ID	1½-inch 1.720 ID	2-inch 2.149 ID	2½-inch 2.601 ID	3-inch 3.166 ID	3½-inch 3.620 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet							
2	.15	.04	.02					2
4	.54	.17	.09	.03	.01			4
6	1.15	.37	.19	.06	.02			6
8	1.97	.63	.32	.11	.04	.01		8
10	2.98	.95	.49	.16	.06	.02	.01	10
15	6.32	2.03	1.04	.35	.14	.05	.02	15
20	10.79	3.46	1.78	.60	.23	.09	.04	20
25	16.30	5.22	2.70	.91	.36	.13	.07	25
30	22.86	7.32	3.78	1.27	.50	.19	.10	30
35		9.75	5.03	1.70	.67	.25	.13	35
40		12.46	6.46	2.18	.86	.32	.17	40
45		15.51	8.02	2.71	1.07	.40	.21	45
50		18.87	9.75	3.30	1.30	.49	.25	50
55		22.48	11.64	3.94	1.54	.59	.30	55
60			13.64	4.62	1.81	.69	.36	60
65			15.85	5.36	2.10	.80	.41	65
70			18.19	6.14	2.42	.92	.47	70
75			20.65	6.99	2.75	1.06	.55	75
80			23.28	7.86	3.10	1.19	.62	80
85				8.81	3.47	1.33	.69	85
90				9.79	3.85	1.48	.77	90
95				10.82	4.25	1.64	.85	95
100				11.89	4.69	1.80	.93	100
110				14.21	5.59	2.14	1.11	110
120				16.69	6.56	2.52	1.31	120
130				19.35	7.63	2.92	1.53	130
140				22.21	8.73	3.36	1.75	140
150					9.94	3.82	1.99	150
160					11.20	4.29	2.24	160
170					12.51	4.80	2.50	170
180					13.90	5.35	2.79	180
190					15.39	5.92	3.08	190
200					16.91	6.50	3.38	200
220					20.19	7.77	4.04	220
240					23.73	9.12	4.76	240
260						10.57	5.51	260
280						12.11	6.32	280
300						13.78	7.18	300
320						15.52	8.10	320
340						17.37	9.07	340
360						19.27	10.08	360
380						21.33	11.13	380
400						23.45	12.22	400
420							13.40	420
440							14.59	440
460							15.86	460
480							17.15	480
500							18.50	500

Table based on Hazen-Williams equation - $C_1 = 150$

To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Exhibit 3-7 Friction head loss in semirigid plastic irrigation pipelines manufactured of PVC or ABS compounds. Standard dimension ratio - SDR = 21. (Ref. SCS - Fort Worth, Texas, 1967)

Sheet 1 of 5

For IPS Pipe

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet						
15	.01						15
20	.02						20
25	.04	.01					25
30	.05	.02					30
35	.07	.02	.01				35
40	.09	.03	.01				40
45	.12	.04	.01				45
50	.14	.05	.02				50
55	.17	.06	.02				55
60	.20	.07	.03				60
65	.23	.08	.03	.01			65
70	.27	.09	.04	.01			70
75	.31	.11	.04	.01			75
80	.35	.12	.05	.01			80
85	.39	.14	.05	.01			85
90	.43	.15	.06	.01			90
95	.48	.17	.07	.02			95
100	.52	.19	.07	.02			100
110	.63	.22	.09	.02			110
120	.74	.26	.10	.03	.01		120
130	.85	.30	.12	.03	.01		130
140	.98	.35	.14	.04	.01		140
150	1.11	.40	.16	.05	.01		150
160	1.26	.44	.19	.05	.01		160
170	1.41	.49	.21	.06	.02		170
180	1.57	.55	.24	.07	.02	.01	180
190	1.73	.61	.26	.07	.02	.01	190
200	1.90	.67	.29	.08	.02	.01	200
220	2.28	.81	.34	.09	.03	.01	220
240	2.67	.95	.40	.10	.03	.01	240
260	3.10	1.10	.46	.12	.04	.02	260
280	3.56	1.26	.54	.14	.05	.02	280
300	4.04	1.43	.61	.17	.05	.02	300
320	4.56	1.62	.69	.19	.06	.03	320
340	5.10	1.82	.77	.21	.07	.03	340
360	5.67	2.02	.86	.24	.08	.03	360
380	6.26	2.22	.95	.26	.09	.04	380
400	6.90	2.45	1.04	.28	.10	.04	400
420	7.55	2.69	1.14	.31	.10	.05	420
440	8.23	2.92	1.25	.34	.11	.05	440
460	8.94	3.18	1.35	.37	.12	.06	460
480	9.67	3.44	1.46	.41	.14	.06	480
500	10.42	3.70	1.58	.43	.15	.06	500
550	12.44	4.42	1.89	.52	.18	.07	550
600	14.61	5.21	2.22	.61	.21	.09	600

SDR No.	Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Exhibit 3-7 **Friction head loss in semirigid plastic irrigation pipelines manufactured of PVC or ABS compounds. Standard dimension ratio - SDR = 21. (Ref. SCS - Fort Worth, Texas, 1967)**

For 125 Pipe

Q Gallons per min.	4-inch 4.072 ID	5-inch 5.033 ID	6-inch 5.993 ID	8-inch 7.805 ID	10-inch 9.728 ID	12-inch 11.538 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet						
600	14.61	5.21	2.22	.61	.21	.09	600
650	16.94	6.04	2.58	.71	.24	.10	650
700	19.45	6.92	2.96	.81	.28	.12	700
750	22.08	7.87	3.36	.93	.32	.14	750
800		8.88	3.78	1.04	.36	.16	800
850		9.93	4.24	1.17	.40	.17	850
900		11.05	4.71	1.30	.44	.19	900
950		12.18	5.21	1.44	.49	.21	950
1000		13.40	5.73	1.58	.54	.23	1000
1050		14.67	6.27	1.73	.59	.26	1050
1100		16.00	6.83	1.88	.65	.28	1100
1150		17.39	7.41	2.05	.70	.30	1150
1200		18.80	8.02	2.21	.76	.33	1200
1250		20.27	8.66	2.39	.82	.35	1250
1300		21.78	9.32	2.57	.88	.37	1300
1350			9.99	2.76	.95	.40	1350
1400			10.66	2.95	1.01	.43	1400
1450			11.40	3.16	1.08	.47	1450
1500			12.13	3.35	1.15	.50	1500
1600			13.68	3.78	1.30	.56	1600
1700			15.29	4.23	1.45	.62	1700
1800			16.99	4.70	1.62	.70	1800
1900			18.81	5.20	1.79	.77	1900
2000			20.66	5.72	1.97	.84	2000
2100			22.61	6.26	2.15	.93	2100
2200			24.67	6.83	2.34	1.01	2200
2300				7.42	2.55	1.10	2300
2400				8.02	2.76	1.19	2400
2500				8.67	2.97	1.29	2500
2600				9.31	3.20	1.39	2600
2700				9.98	3.43	1.49	2700
2800				10.67	3.67	1.59	2800
2900				11.39	3.92	1.69	2900
3000				12.10	4.17	1.81	3000
3100				12.89	4.43	1.92	3100
3200				13.66	4.71	2.04	3200
3300				14.46	4.97	2.15	3300
3400				15.29	5.27	2.28	3400
3500				16.11	5.56	2.41	3500
3600				16.99	5.85	2.53	3600
3700				17.89	6.17	2.67	3700
3800				18.76	6.47	2.80	3800
3900				19.69	6.79	2.94	3900
4000				20.67	7.11	3.08	4000

SDR No.	Factor
13.5	1.35
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Exhibit 3-7 Friction head loss in semirigid plastic irrigation pipelines manufactured of PVC or ABS compounds. Standard dimension ratio - SDR = 21. (Ref. SCS - Fort Worth, Texas, 1967)

For PIP Pipe

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet					
15	.02					15
20	.04					20
25	.06					25
30	.09	.01				30
35	.12	.02				35
40	.15	.02				40
45	.18	.03				45
50	.22	.03				50
55	.27	.04				55
60	.31	.05				60
65	.36	.05	.01			65
70	.42	.06	.02			70
75	.47	.07	.02			75
80	.53	.08	.02			80
85	.60	.09	.02			85
90	.66	.10	.02			90
95	.73	.11	.03			95
100	.80	.12	.03			100
110	.96	.14	.03			110
120	1.13	.16	.04	.01		120
130	1.31	.19	.05	.02		130
140	1.50	.22	.05	.02		140
150	1.70	.25	.06	.02		150
160	1.92	.28	.07	.02		160
170	2.15	.31	.08	.03		170
180	2.39	.35	.09	.03		180
190	2.64	.38	.10	.03		190
200	2.90	.42	.11	.04	.01	200
220	3.46	.50	.13	.04	.02	220
240	4.07	.59	.15	.05	.02	240
260	4.72	.68	.17	.06	.02	260
280	5.41	.78	.20	.07	.03	280
300	6.15	.89	.22	.08	.03	300
320	6.93	1.00	.25	.08	.03	320
340	7.76	1.12	.28	.09	.04	340
360	8.62	1.25	.31	.11	.04	360
380	9.53	1.38	.35	.12	.05	380
400	10.48	1.52	.38	.13	.05	400
420	11.47	1.66	.42	.14	.06	420
440	12.50	1.81	.45	.15	.06	440
460	13.58	1.96	.49	.17	.07	460
480	14.69	2.13	.53	.18	.07	480
500	15.84	2.29	.57	.19	.08	500
550	18.90	2.74	.69	.23	.10	550
600	22.21	3.21	.81	.27	.11	600

Table based on Hazen-Williams equation - $C_1 = 150$.

To find friction head loss in PVC or ABS pipe having a standard dimension ratio other than 21, the values in the table should be multiplied by the appropriate conversion factor shown below:

SDR No.	Conversion Factor
13.5	1.34
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Exhibit 3-7 Friction head loss in semirigid plastic irrigation pipelines manufactured of PVC or ABS compounds. Standard dimension ratio - SDR = 21. (Ref. SCS - Fort Worth, Texas, 1967)

For PIP Pipe

Q Gallons per min.	4-inch 3.736 ID	6-inch 5.556 ID	8-inch 7.382 ID	10-inch 9.228 ID	12-inch 11.074 ID	Q Gallons per min.
	Friction Head Loss in Feet per Hundred Feet					
650		3.73	.93	.31	.13	650
700		4.28	1.07	.36	.15	700
750		4.86	1.22	.41	.17	750
800		5.47	1.37	.46	.19	800
850		6.13	1.53	.52	.21	850
900		6.81	1.71	.58	.24	900
950		7.53	1.89	.64	.26	950
1000		8.28	2.07	.70	.29	1000
1050		9.06	2.27	.77	.31	1050
1100		9.87	2.47	.83	.34	1100
1150		10.72	2.69	.91	.37	1150
1200		11.60	2.91	.98	.40	1200
1250		12.51	3.13	1.06	.43	1250
1300		13.45	3.37	1.14	.47	1300
1350		14.43	3.61	1.22	.50	1350
1400		15.43	3.87	1.30	.54	1400
1450		16.47	4.13	1.39	.57	1450
1500		17.54	4.39	1.48	.61	1500
1600		19.76	4.95	1.67	.69	1600
1700		22.11	5.54	1.87	.77	1700
1800		24.58	6.16	2.08	.85	1800
1900			6.81	2.29	.94	1900
2000			7.49	2.52	1.04	2000
2100			8.19	2.76	1.14	2100
2200			8.93	3.01	1.24	2200
2300			9.70	3.27	1.35	2300
2400			10.49	3.54	1.46	2400
2500			11.32	3.82	1.57	2500
2600			12.17	4.10	1.69	2600
2700			13.05	4.40	1.81	2700
2800			13.96	4.71	1.94	2800
2900			14.90	5.02	2.07	2900
3000			15.86	5.35	2.20	3000
3100			16.85	5.68	2.34	3100
3200			17.88	6.03	2.48	3200
3300			18.92	6.38	2.62	3300
3400			20.00	6.74	2.77	3400
3500			21.10	7.11	2.93	3500
3600			22.23	7.50	3.08	3600
3700			23.39	7.89	3.24	3700
3800			24.57	8.28	3.41	3800
3900				8.69	3.58	3900
4000				9.11	3.75	4000

SDR No.	Factor
13.5	1.34
17	1.13
21	1.00
26	.91
32.5	.84
41	.785
51	.75

Exhibit 3-7 Friction head loss in semirigid plastic irrigation pipelines manufactured of PVC or ABS compounds. Standard dimension ratio - SDR = 21. (Ref. SCS - Fort Worth, Texas, 1967)

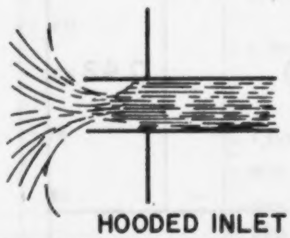
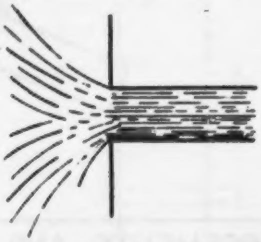
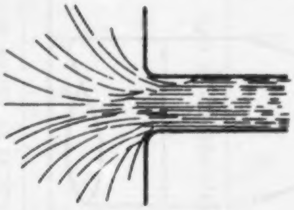
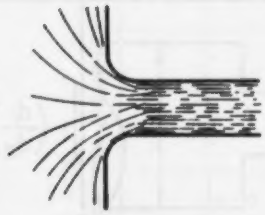
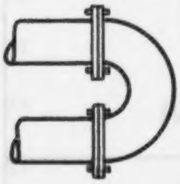
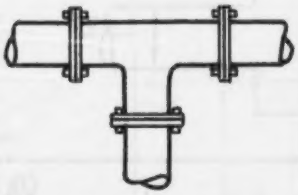
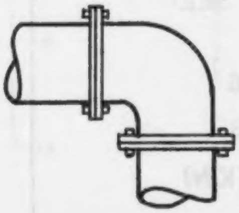
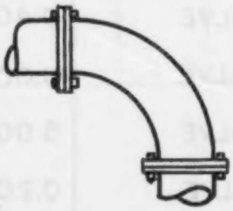
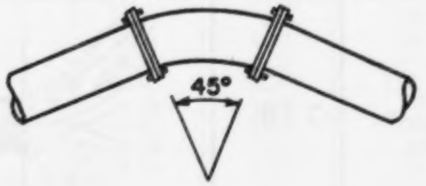
PIPE ENTRANCES			
INWARD PROJECTING PIPE	K_e	SHARP-CORNERED	K_e
	0.78		0.50
HOODED INLET	1.00		
SLIGHTLY ROUNDED	K_e	BELL MOUTH	K_e
	0.23		0.04
PIPE BENDS			
RETURN BEND	K_{RB}	STANDARD-TEE	K_{ST}
	2.20		1.80
STANDARD 90°-ELBOW	K_{90}	LONG RADIUS ELBOW	K_{LR}
	0.90		0.60

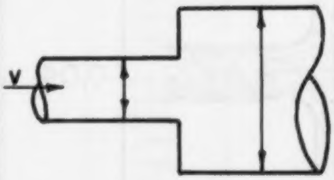
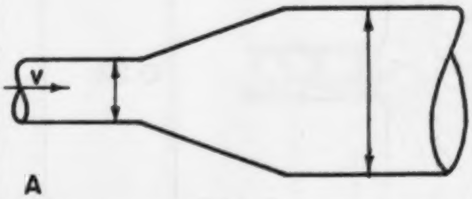
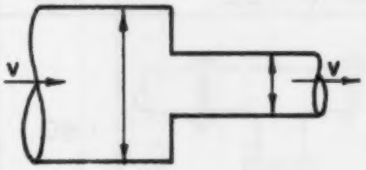
Exhibit 3-8 Head loss coefficients for pipe entrances and bends

(Sheet 1 of 2)

PIPE BENDS

45° ELBOW	K_{45}
	0.42

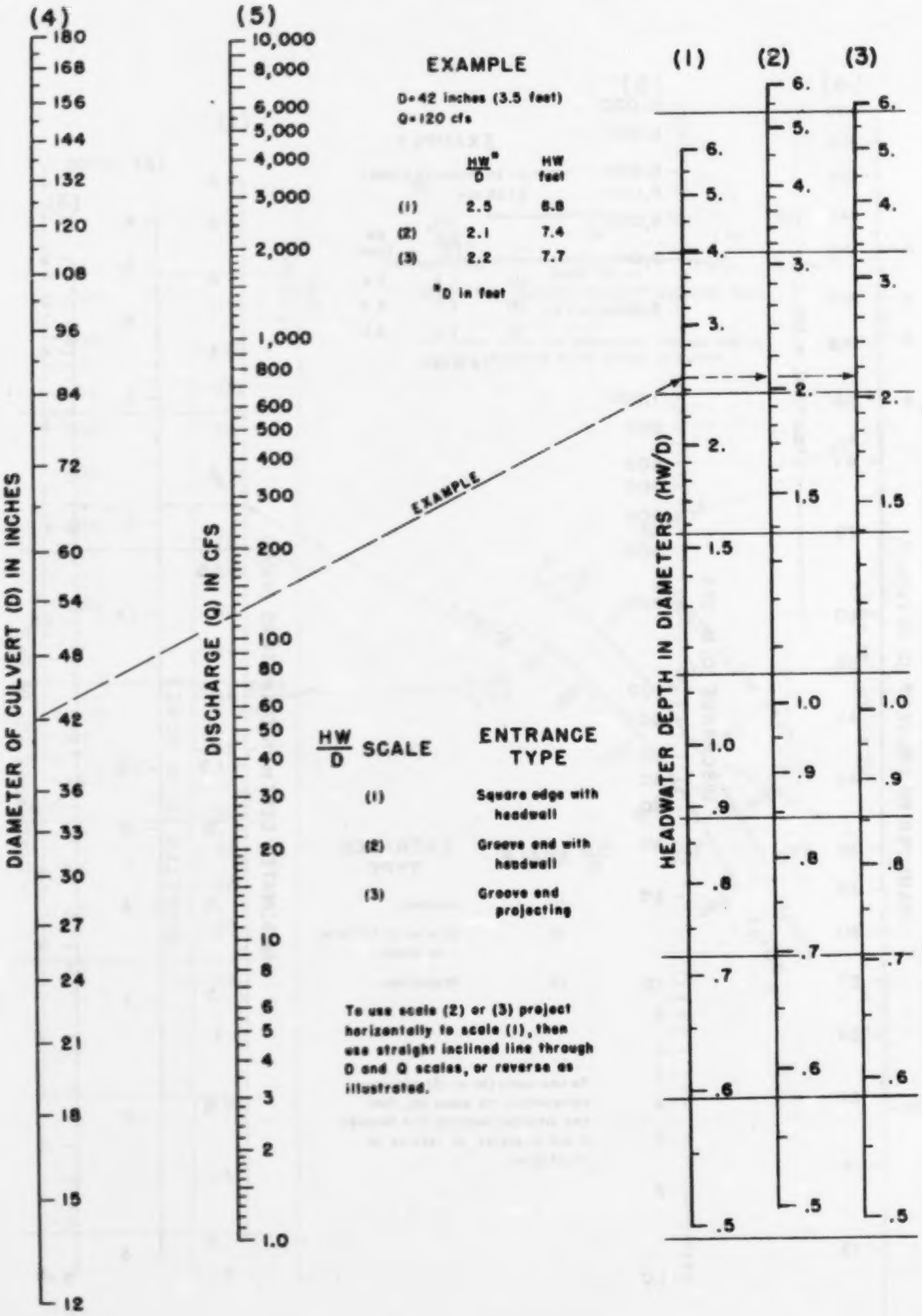
ENLARGEMENTS AND CONTRACTIONS

SUDDEN ENLARGEMENT	K_{SE}	GRADUAL ENLARGEMENT
	$\left[1-\left(\frac{d_1}{d_2}\right)^2\right]^2$	 A
SUDDEN CONTRACTION		K FACTORS FOR A & B SEE:
B 		REFERENCE: HANDBOOK OF HYDRAULICS BY H.W. KING PAGES 6 - 18 (FOURTH EDITION)

VALVES

WIDE OPEN	K	PARTIALLY CLOSED
FOOT VALVE	0.40	FOR K FACTORS SEE: REFERENCE: BY H.W. KING PAGES 6 - 18 (FOURTH EDITION)
GLOBE VALVE	10.00	
ANGLE VALVE	5.00	
GATE VALVE	0.20	

Exhibit 3-8 Head loss coefficients for pipe entrances and bends
(Sheet 2 of 2)



EXAMPLE

D=42 inches (3.5 feet)
Q=120 cfs

	$\frac{HW}{D}$*	HW feet
(1)	2.5	8.8
(2)	2.1	7.4
(3)	2.2	7.7

*D in feet

$\frac{HW}{D}$ SCALE	ENTRANCE TYPE
(1)	Square edge with headwall
(2)	Groove end with headwall
(3)	Groove end projecting

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

Exhibit 3-9 Headwater depth for concrete pipe culverts with inlet control (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

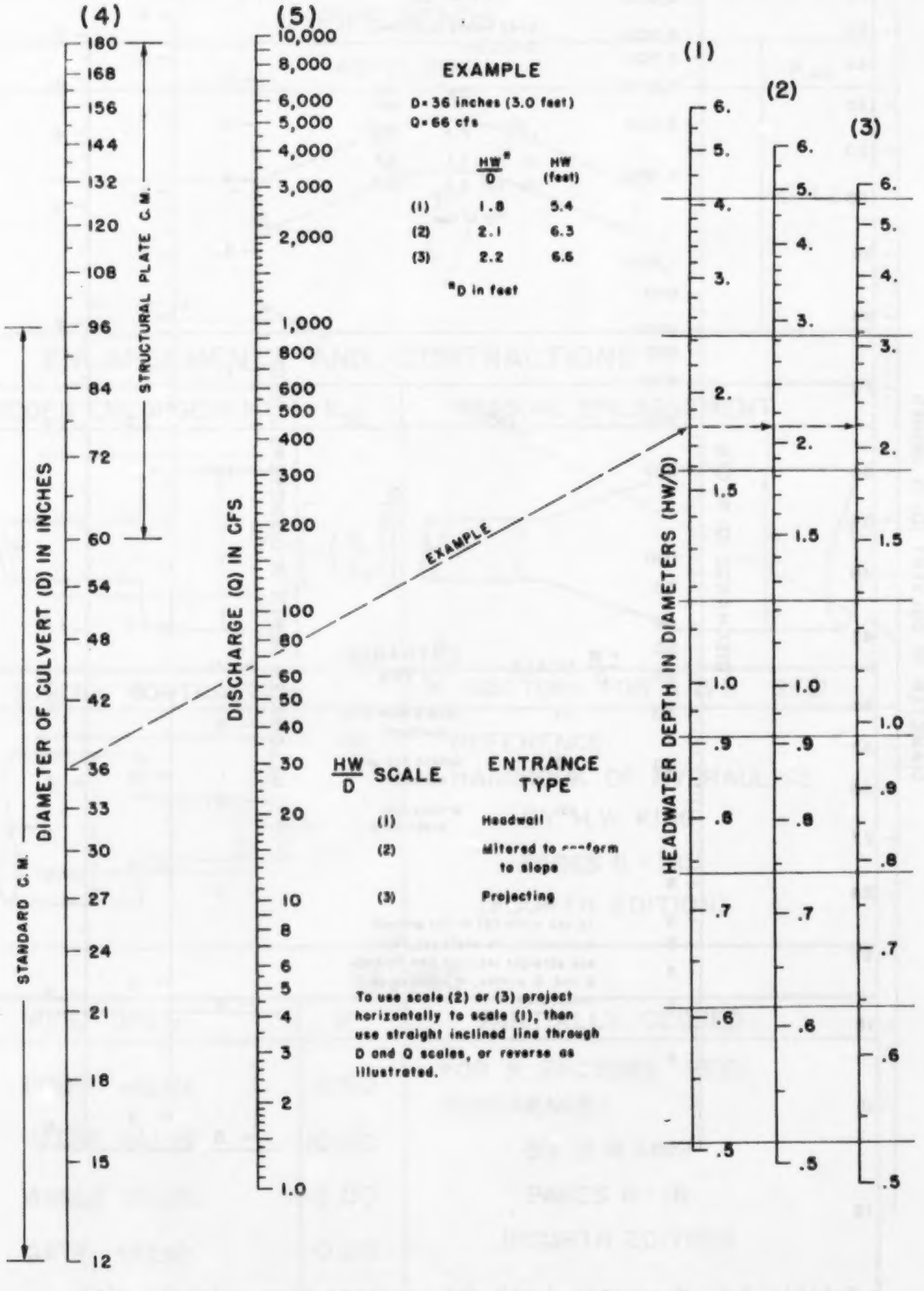


Exhibit 3-10 Headwater depth for CM pipe culverts with inlet control (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

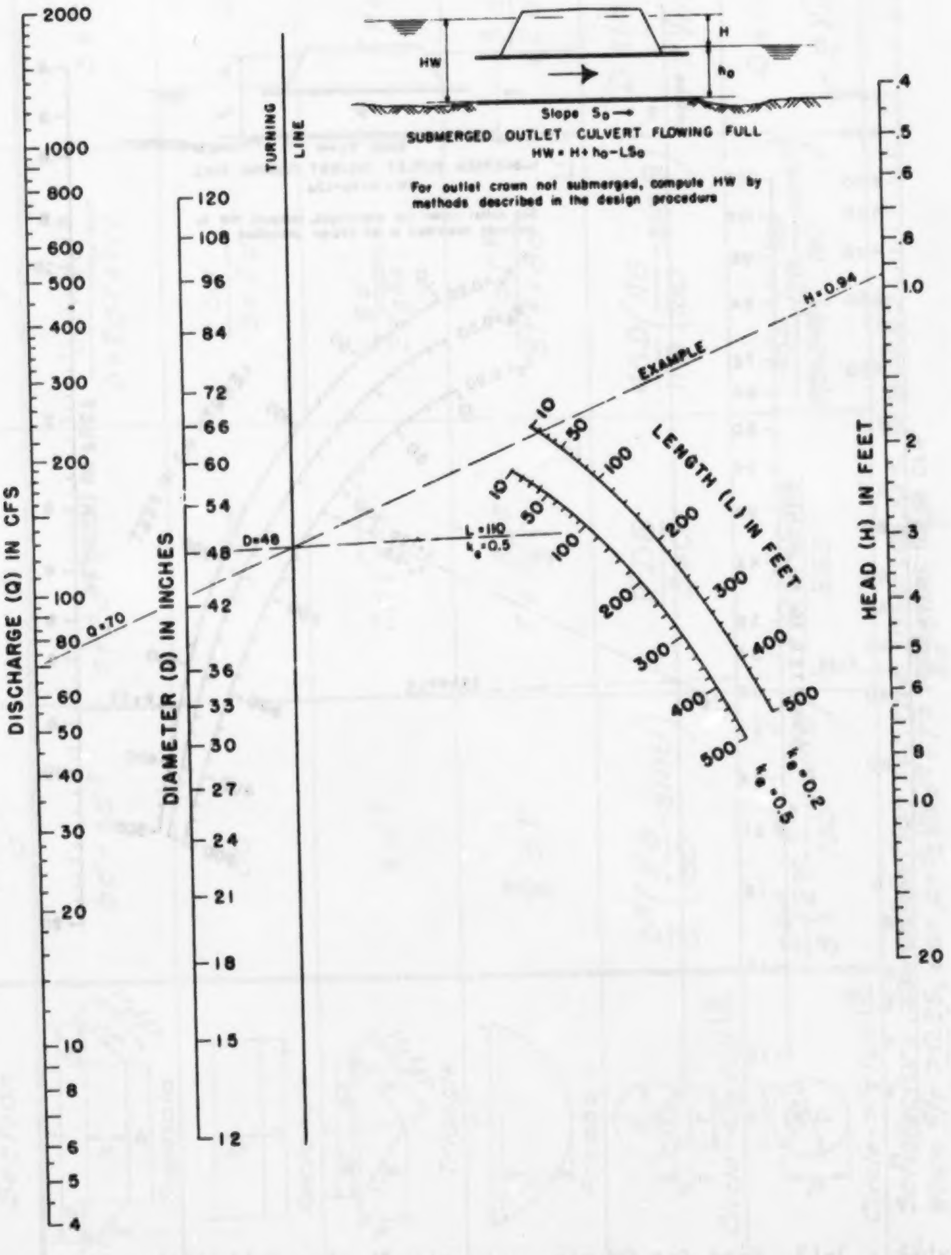


Exhibit 3-11 Head for concrete pipe culverts flowing full with outlet control n = 0.012 (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

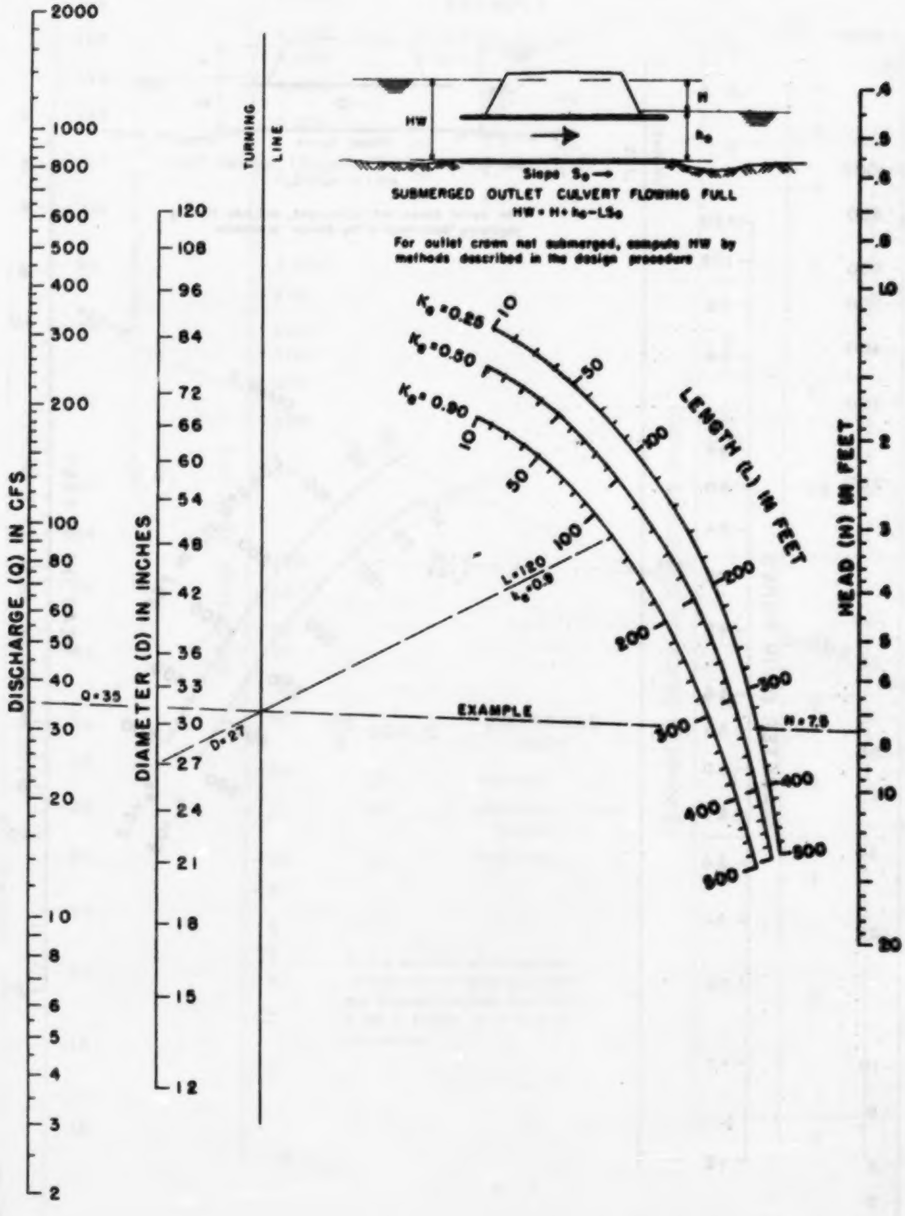
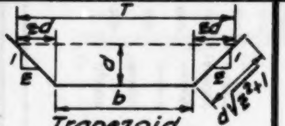
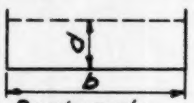
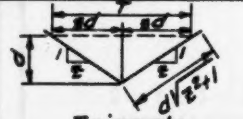
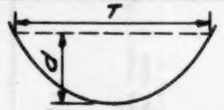
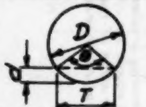
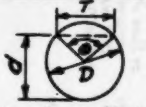


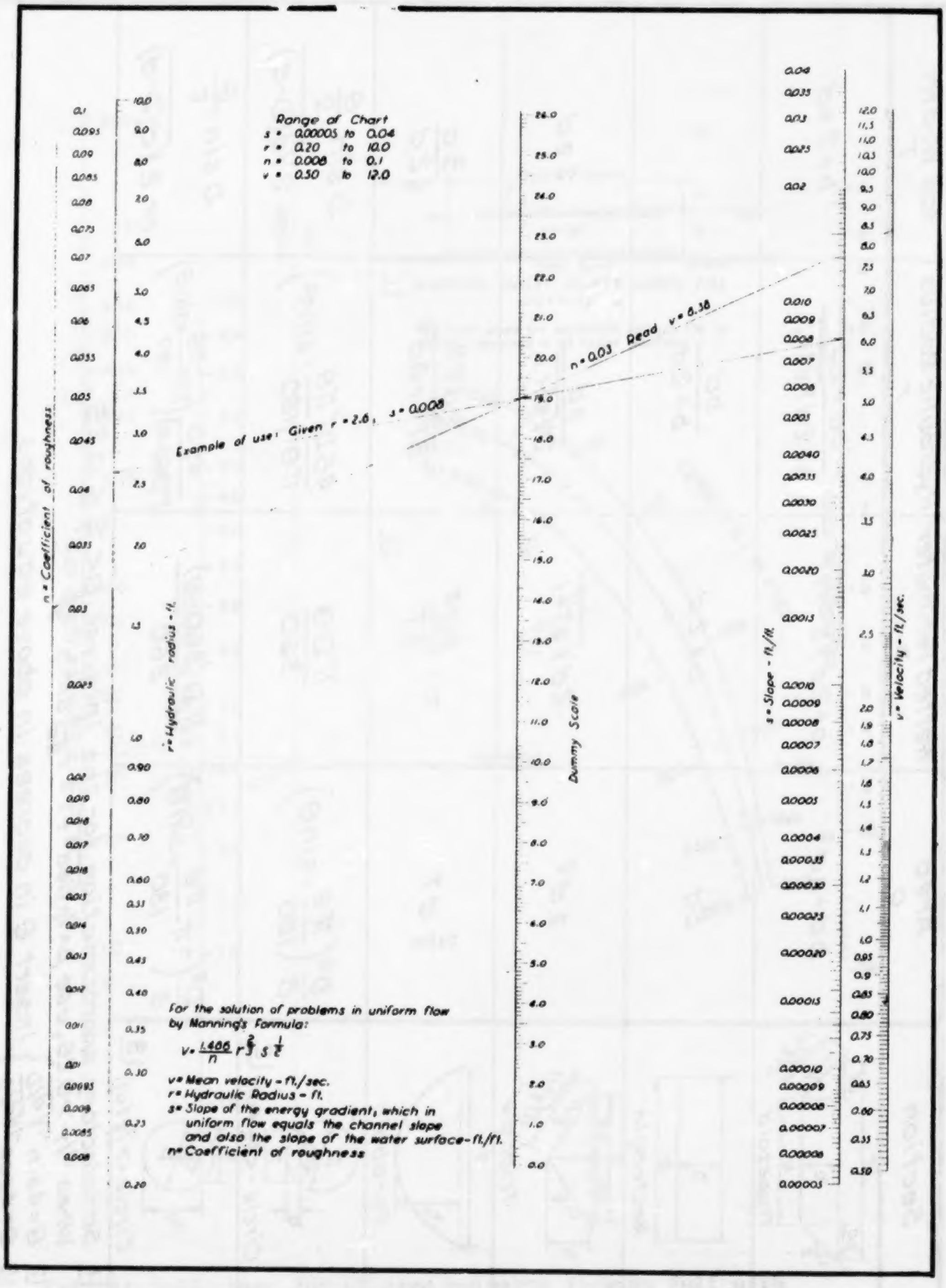
Exhibit 3-12 Head for CM pipe culverts flowing full with outlet control n = 0.024 (Ref. Hyd. Eng. Cir. No. 5, USBPR, 1965)

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 T zd zd d b 1 z 1 z $d\sqrt{z^2+1}$ Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$
 Circle - < ½ full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle - > ½ full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

[1] Satisfactory approximation for the interval $0<\frac{d}{T}\leq 0.25$
When $d/T > 0.25$, use $p=\frac{1}{2}\sqrt{16d^2+T^2}+\frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta=4\sin^{-1}\sqrt{d/D}$
[3] $\theta=4\cos^{-1}\sqrt{d/D}$ } Insert θ in degrees in above equations

Exhibit 3-13 Elements of channel sections (Ref. NEH Section 5, ES-33)



For the solution of problems in uniform flow by Manning's Formula:

$$v = \frac{1.486}{n} r^{\frac{2}{3}} s^{\frac{1}{2}}$$

v = Mean velocity - ft./sec.
r = Hydraulic Radius - ft.
s = Slope of the energy gradient, which in uniform flow equals the channel slope and also the slope of the water surface - ft./ft.
n = Coefficient of roughness

Exhibit 3-14 Solution of Manning's formula for uniform flow (Ref. NEH Section 5, ES-54)

Sheet 1 of 4

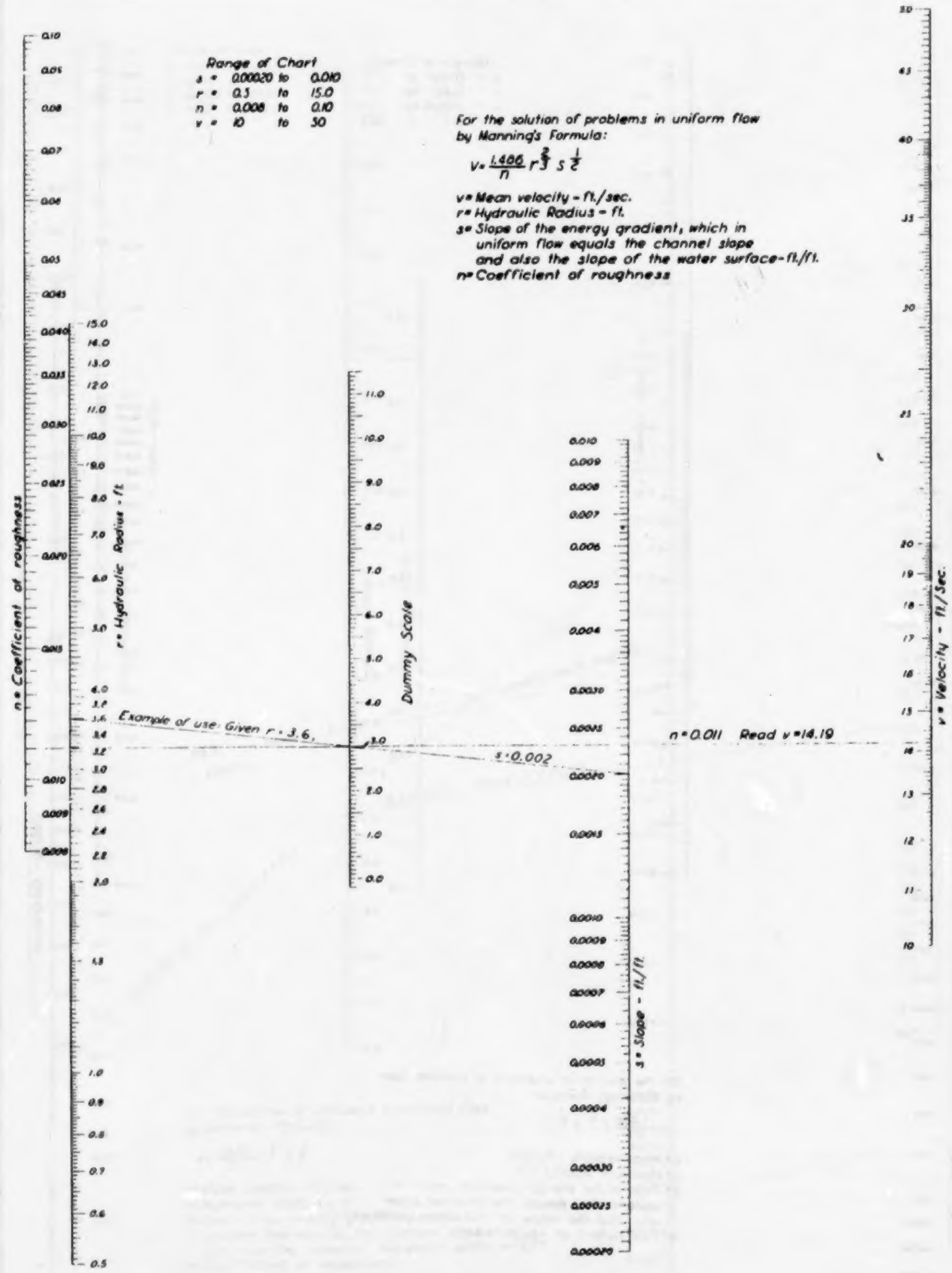
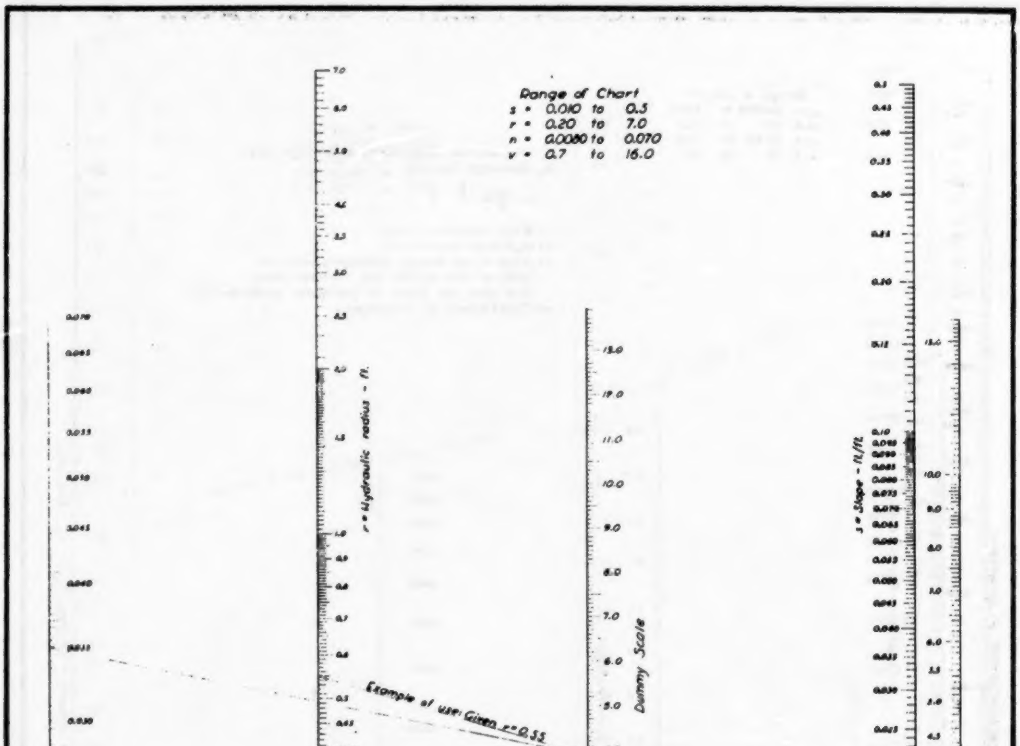


Exhibit 3-14 Solution of Manning's formula for uniform flow (Ref. NEH Section 5, ES-54) Sheet 2 of 4



Range of Chart
s = 0.010 to 0.5
r = 0.20 to 7.0
n = 0.0080 to 0.070
v = 0.7 to 16.0

For the solution of problems in uniform flow by Manning's Formula:

$$v = \frac{1.486}{n} r^{\frac{2}{3}} s^{\frac{1}{2}}$$

v = Mean velocity - ft./sec.
r = Hydraulic Radius - ft.
s = Slope of the energy gradient, which in uniform flow equals the channel slope and also the slope of the water surface - ft./ft.
n = Coefficient of roughness

Exhibit 3-14 Solution of Manning's formula for uniform flow (Ref. NEH Section 5, ES-54)

Sheet 3 of 4

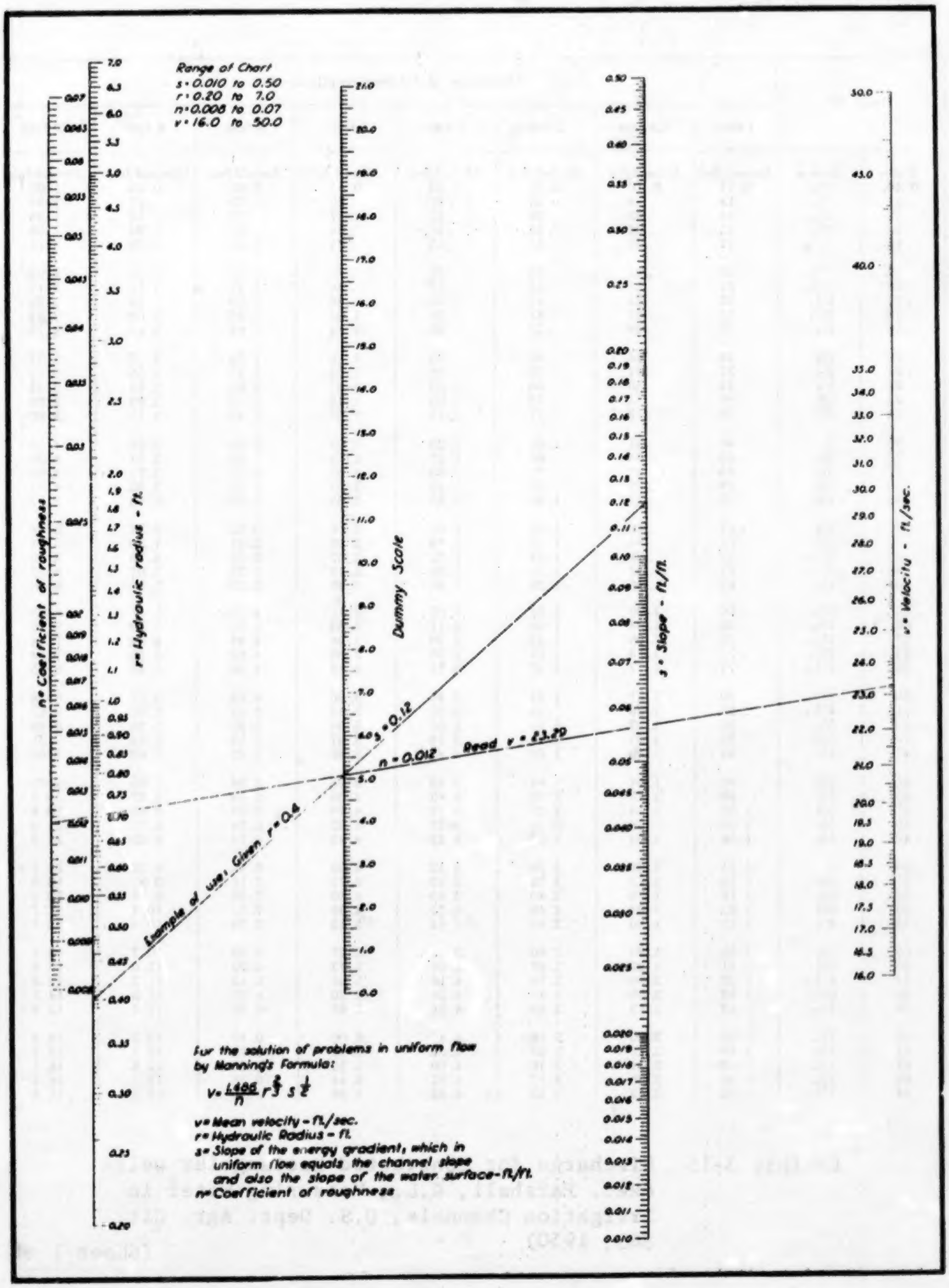


Exhibit 3-14 Solution of Manning's formula for uniform flow (Ref. NEH Section 5, ES-54)

Sheet 4 of 4

Head, H[1]		Discharge, *Q*, for crest length, *L*, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.10	1 3/16	0.11	0.16	0.22	0.33	0.44	0.62	0.84	1.05
.11	1 5/16	.12	.18	.25	.37	.50	.73	.97	1.21
.12	1 7/16	.14	.20	.28	.42	.57	.83	1.10	1.38
.13	1 9/16	.15	.22	.32	.47	.64	.93	1.24	1.56
.14	1 11/16	.17	.25	.35	.53	.71	1.04	1.39	1.74
.15	1 13/16	.19	.28	.39	.58	.79	1.15	1.54	1.93
.16	1 15/16	.21	.31	.43	.64	.86	1.27	1.70	2.12
.17	2 1/16	.23	.34	.47	.70	.95	1.39	1.86	2.33
.18	2 3/16	.25	.37	.51	.76	1.03	1.52	2.03	2.53
.19	2 1/4	.27	.40	.55	.83	1.11	1.64	2.20	2.75
.20	2 3/8	.29	.44	.59	.89	1.19	1.78	2.37	2.97
.21	2 1/2	.31	.47	.63	.95	1.28	1.91	2.55	3.19
.22	2 5/8	.34	.50	.68	1.02	1.37	2.05	2.73	3.42
.23	2 3/4	.36	.54	.72	1.09	1.46	2.19	2.92	3.66
.24	2 7/8	.38	.57	.77	1.16	1,55	2.33	3.11	3.90
.25	3	.40	.61	.82	1.23	1.65	2.48	3.31	4.14
.26	3 1/8	.43	.65	.86	1.31	1.75	2.63	3.51	4.39
.27	3 1/4	.45	.68	.91	1.38	1.85	2.78	3.71	4.65
.28	3 3/8	.48	.72	.96	1.46	1.95	2.93	3.92	4.91
.29	3 1/2	.50	.76	1.02	1.53	2.05	3.09	4.13	5.17
.30	3 5/8	.53	.80	1.07	1.61	2.16	3.25	4.34	5.44
.31	3 3/4	.55	.84	1.12	1.69	2.26	3.41	4.56	5.71
.32	3 13/16	.58	.88	1.18	1.77	2.37	3.58	4.78	5.99
.33	3 15/16	.61	.92	1.23	1.86	2.48	3.75	5.01	6.27
.34	4 1/16	.63	.96	1.28	1.94	2.60	3.92	5.24	6.56
.35	4 3/16	.66	1.00	1.34	2.02	2.71	4.09	5.47	6.85
.36	4 5/16	.69	1.04	1.40	2.11	2.82	4.26	5.70	7.14
.37	4 7/16	.72	1.08	1.45	2.20	2.94	4.44	5.94	7.44
.38	4 9/16	.74	1.13	1.51	2.28	3.06	4.62	6.18	7.74
.39	4 11/16	.77	1.17	1.57	2.37	3.18	4.80	6.43	8.05
.40	4 13/16	.80	1.21	1.63	2.46	3.30	4.99	6.67	8.36
.41	4 15/16	.83	1.26	1.69	2.55	3.42	5.17	6.92	8.67
.42	5 1/16	.86	1.30	1.75	2.65	3.54	5.36	7.18	8.99
.43	5 3/16	.89	1.35	1.81	2.74	3.67	5.55	7.43	9.31
.44	5 1/4	.92	1.40	1.88	2.83	3.80	5.75	7.69	9.63
.45	5 3/8	.96	1.44	1.94	2.93	3.93	5.94	7.95	9.96
.46	5 1/2	.99	1.49	2.00	3.03	4.05	6.14	8.22	10.3
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	6.34	8.48	10.6
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	6.54	8.75	11.0
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	6.74	9.03	11.3
.50	6	1.11	1.68	2.26	3.42	4.58	6.95	9.30	11.7
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	7.15	9.58	12.0
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	7.36	9.86	12.4
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	7.57	10.1	12.7
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	7.79	10.4	13.1
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	8.00	10.7	13.4
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	8.22	11.0	13.8
.57	6 13/16	1.35	2.04	2.74	4.15	5.56	8.43	11.3	14.2
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	8.65	11.6	14.5
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	8.88	11.9	14.9
.60	7 3/16	1.45	2.20	2.96	4.47	6.00	9.10	12.2	15.3
.61	7 5/16	1.49	2.25	3.03	4.59	6.14	9.33	12.5	15.7
.62	7 7/16	1.52	2.31	3.10	4.69	6.29	9.55	12.8	16.1
.63	7 9/16	1.56	2.36	3.17	4.81	6.44	9.78	13.1	16.4
.64	7 11/16	1.60	2.42	3.25	4.92	6.59	10.0	13.4	16.8

Exhibit 3-15 Discharge for contracted rectangular weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

(Sheet 1 of 3)

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.65	7 13/16	1.63	2.47	3.32	5.03	6.75	10.2	13.7	17.2
.66	7 15/16	1.67	2.53	3.40	5.15	6.90	10.5	14.0	17.6
.67	8 1/16	1.71	2.59	3.47	5.26	7.05	10.7	14.4	18.0
.68	8 3/16	1.74	2.64	3.56	5.38	7.21	10.9	14.7	18.4
.69	8 1/4	1.78	2.70	3.63	5.49	7.36	11.2	15.0	18.8
.70	8 3/8	1.82	2.76	3.71	5.61	7.52	11.4	15.3	19.2
.71	8 1/2	1.86	2.81	3.78	5.73	7.68	11.7	15.7	19.6
.72	8 5/8	1.90	2.87	3.86	5.85	7.84	11.9	16.0	20.1
.73	8 3/4	1.93	2.93	3.94	5.97	8.00	12.2	16.3	20.5
.74	8 7/8	1.97	2.99	4.02	6.09	8.17	12.4	16.6	20.9
.75	9	2.01	3.05	4.10	6.21	8.33	12.7	17.0	21.3
.76	9 1/8	2.05	3.11	4.18	6.33	8.49	12.9	17.3	21.7
.77	9 1/4	2.09	3.17	4.26	6.45	8.66	13.2	17.7	22.2
.78	9 3/8	2.13	3.23	4.34	6.58	8.82	13.4	18.0	22.6
.79	9 1/2	2.17	3.29	4.42	6.70	8.99	13.7	18.3	23.0
.80	9 5/8	2.21	3.35	4.51	6.83	9.16	13.9	18.7	23.4
.81	9 3/4	2.25	3.41	4.59	6.95	9.33	14.2	19.0	23.9
.82	9 13/16	2.29	3.47	4.67	7.08	9.50	14.4	19.4	24.3
.83	9 15/16	2.33	3.54	4.75	7.21	9.67	14.7	19.7	24.8
.84	10 1/16	2.37	3.60	4.84	7.33	9.84	15.0	20.1	25.2
.85	10 3/16	2.41	3.66	4.92	7.46	10.0	15.2	20.4	25.7
.86	10 5/16	2.46	3.72	5.01	7.59	10.2	15.5	20.8	26.1
.87	10 7/16	2.50	3.79	5.10	7.72	10.4	15.7	21.1	26.6
.88	10 9/16	2.54	3.85	5.18	7.85	10.5	16.0	21.5	27.0
.89	10 11/16	2.58	3.92	5.27	7.99	10.7	16.3	21.9	27.5
.90	10 13/16	2.62	3.98	5.35	8.12	10.9	16.5	22.2	27.9
.91	10 15/16	2.67	4.05	5.44	8.25	11.1	16.8	22.6	28.4
.92	11 1/16	2.71	4.11	5.53	8.38	11.2	17.1	23.0	28.8
.93	11 3/16	2.75	4.18	5.62	8.52	11.4	17.4	23.3	29.3
.94	11 1/4	2.79	4.24	5.71	8.65	11.6	17.6	23.7	29.8
.95	11 3/8	2.84	4.31	5.80	8.79	11.8	17.9	24.1	30.2
.96	11 1/2	2.88	4.37	5.89	8.93	12.0	18.2	24.5	30.7
.97	11 5/8	2.93	4.44	5.98	9.06	12.2	18.5	24.8	31.2
.98	11 3/4	2.97	4.51	6.07	9.20	12.3	18.8	25.2	31.7
.99	11 7/8	3.01	4.57	6.15	9.34	12.5	19.0	25.6	32.2
1.00	12	3.06	4.64	6.25	9.48	12.7	19.3	26.0	32.6
1.01	12 1/8	------	4.71	6.34	9.62	12.9	19.6	26.4	33.1
1.02	12 1/4	------	4.78	6.43	9.76	13.1	19.9	26.7	33.6
1.03	12 3/8	------	4.85	6.52	9.90	13.3	20.2	27.1	34.1
1.04	12 1/2	------	4.92	6.62	10.0	13.5	20.5	27.5	34.6
1.05	12 5/8	------	4.98	6.71	10.2	13.7	20.7	27.9	35.1
1.06	12 3/4	------	5.05	6.80	10.3	13.8	21.0	28.3	35.6
1.07	12 13/16	------	5.12	6.90	10.5	14.0	21.3	28.7	36.1
1.08	12 15/16	------	5.20	6.99	10.6	14.2	21.6	29.1	36.6
1.09	13 1/16	------	5.26	7.09	10.8	14.4	21.9	29.5	37.1
1.10	13 3/16	------	5.34	7.19	10.9	14.6	22.2	29.9	37.6
1.11	13 5/16	------	5.41	7.28	11.0	14.8	22.5	30.3	38.1
1.12	13 7/16	------	5.48	7.38	11.2	15.0	22.8	30.7	38.6
1.13	13 9/16	------	5.55	7.47	11.3	15.2	23.1	31.1	39.1
1.14	13 11/16	------	5.62	7.57	11.5	15.4	23.4	31.5	39.6
1.15	13 13/16	------	5.69	7.66	11.6	15.6	23.7	31.9	40.1
1.16	13 15/16	------	5.77	7.76	11.8	15.8	24.0	32.3	40.6
1.17	14 1/16	------	5.84	7.86	11.9	16.0	24.3	32.7	41.2
1.18	14 3/16	------	5.91	7.96	12.1	16.2	24.6	33.1	41.7
1.19	14 1/4	------	5.98	8.06	12.2	16.4	24.9	33.6	42.2

Exhibit 3-15 Discharge for contracted rectangular weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

(Sheet 2 of 3)

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
1. 20	14⅜	......	6. 06	8. 16	12. 4	16. 6	25. 2	34. 0	42. 7
1. 21	14½	......	6. 13	8. 26	12. 5	16. 8	25. 5	34. 4	43. 2
1. 22	14⅝	......	6. 20	8. 35	12. 7	17. 0	25. 8	34. 8	43. 8
1. 23	14¾	......	6. 28	8. 46	12. 8	17. 2	26. 2	35. 2	44. 3
1. 24	14⅞	......	6. 35	8. 56	13. 0	17. 4	26. 5	35. 6	44. 8
1. 25	15	......	6. 43	8. 66	13. 1	17. 6	26. 8	36. 1	45. 4
1. 26	15⅛	......	....	....	13. 3	17. 9	27. 1	36. 5	45. 9
1. 27	15¼	......	....	....	13. 4	18. 1	27. 4	36. 9	46. 4
1. 28	15⅜	......	....	....	13. 6	18. 3	27. 7	37. 3	47. 0
1. 29	15½	......	....	....	13. 8	18. 5	28. 0	37. 8	47. 5
1. 30	15⅝	......	....	....	13. 9	18. 7	28. 3	38. 2	48. 1
1. 31	15¾	......	....	....	14. 1	18. 9	28. 7	38. 6	48. 6
1. 32	15¹³⁄₁₆	......	....	....	11. 2	19. 1	29. 0	39. 1	49. 2
1. 33	15¹⁵⁄₁₆	......	....	....	14. 4	19. 3	29. 3	39. 5	49. 7
1. 34	16¹⁄₁₆	......	....	....	14. 6	19. 6	29. 6	39. 9	50. 3
1. 35	16³⁄₁₆	......	....	....	14. 7	19. 8	30. 0	40. 4	50. 8
1. 36	16⁵⁄₁₆	......	....	....	14. 9	20. 0	30. 3	40. 8	51. 4
1. 37	16⁷⁄₁₆	......	....	....	15. 0	20. 2	30. 6	41. 3	51. 9
1. 38	16⁹⁄₁₆	......	....	....	15. 2	20. 4	30. 9	41. 7	52. 5
1. 39	16¹¹⁄₁₆	......	....	....	15. 4	20. 6	31. 3	42. 1	53. 1
1. 40	16¹³⁄₁₆	......	....	....	15. 5	20. 9	31. 6	42. 6	53. 6
1. 41	16¹⁵⁄₁₆	......	....	....	15. 7	21. 1	31. 9	43. 0	54. 2
1. 42	17¹⁄₁₆	......	....	....	15. 9	21. 3	32. 2	43. 5	54. 7
1. 43	17³⁄₁₆	......	....	....	16. 0	21. 5	32. 6	43. 9	55. 3
1. 44	17¼	......	....	....	16. 2	21. 7	32. 9	44. 4	55. 9
1. 45	17⅜	......	....	....	16. 3	22. 0	33. 2	44. 8	56. 5
1. 46	17½	......	....	....	16. 5	22. 2	33. 6	45. 3	57. 0
1. 47	17⅝	......	....	....	16. 7	22. 4	33. 9	45. 7	57. 6
1. 48	17¾	......	....	....	16. 9	22. 6	34. 2	46. 2	58. 2
1. 49	17⅞	......	....	....	17. 0	22. 9	34. 6	46. 6	58. 8
1. 50	18	......	....	....	17. 2	23. 1	34. 9	47. 1	59. 3

[1] Values of discharge for heads up to 0.20 foot (crest lengths 1, 1.5, 2, 3, and 4 feet) do not follow the formula, but are taken directly from the calibration curve. The discharge for heads 0.10 to 1.5 feet for the 6-, 8-, and 10-foot weirs are as computed by the formula $Q=3.33\ (L-0.2H)\ H^{3/2}$.

Exhibit 3-15 Discharge for contracted rectangular weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

(Sheet 3 of 3)

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0. 10	1 3/16	0. 11	0. 16	0. 23	0. 33	0. 44	0. 64	0. 85	1. 06
. 11	1 5/16	. 12	. 18	. 26	. 38	. 50	. 74	. 98	1. 23
. 12	1 7/16	. 14	. 21	. 29	. 43	. 57	. 84	1. 12	1. 40
. 13	1 9/16	. 16	. 24	. 32	. 48	. 64	. 95	1. 26	1. 58
. 14	1 11/16	. 17	. 26	. 36	. 54	. 71	1. 06	1. 41	1. 73
. 15	1 13/16	. 19	. 29	. 39	. 59	. 79	1. 17	1. 56	1. 96
. 16	1 15/16	. 21	. 32	. 43	. 65	. 87	1. 29	1. 72	2. 15
. 17	2 1/16	. 23	. 36	. 47	. 71	. 96	1. 41	1. 89	2. 36
. 18	2 3/16	. 25	. 39	. 51	. 77	1. 04	1. 54	2. 06	2. 57
. 19	2 1/4	. 28	. 42	. 56	. 83	1. 12	1. 67	2. 23	2. 79
. 20	2 3/8	. 30	. 45	. 60	. 90	1. 20	1. 81	2. 41	3. 01
. 21	2 1/2	. 32	. 48	. 64	. 97	1. 29	1. 94	2. 59	3. 24
. 22	2 5/8	. 35	. 52	. 69	1. 04	1. 38	2. 08	2. 78	3. 47
. 23	2 3/4	. 37	. 55	. 74	1. 11	1. 47	2. 23	2. 97	3. 71
. 24	2 7/8	. 39	. 59	. 79	1. 18	1. 57	2. 38	3. 17	3. 96
. 25	3	. 42	. 63	. 84	1. 25	1. 67	2. 53	3. 37	4. 21
. 26	3 1/8	. 45	. 67	. 89	1. 33	1. 77	2. 68	3. 57	4. 46
. 27	3 1/4	. 47	. 70	. 94	1. 40	1. 87	2. 83	3. 78	4. 72
. 28	3 3/8	. 50	. 74	. 99	1. 48	1. 97	2. 99	3. 99	4. 99
. 29	3 1/2	. 53	. 79	1. 04	1. 56	2. 08	3. 15	4. 21	5. 26
. 30	3 5/8	. 56	. 83	1. 10	1. 64	2. 19	3. 32	4. 43	5. 53
. 31	3 3/4	. 59	. 87	1. 15	1. 73	2. 30	3. 49	4. 65	5. 81
. 32	3 13/16	. 61	. 91	1. 21	1. 80	2. 41	3. 66	4. 88	6. 09
. 33	3 15/16	. 64	. 95	1. 27	1. 89	2. 52	3. 83	5. 11	6. 38
. 34	4 1/16	. 67	1. 00	1. 32	1. 98	2. 64	4. 00	5. 34	6. 67
. 35	4 3/16	. 70	1. 04	1. 38	2. 07	2. 75	4. 18	5. 58	6. 97
. 36	4 5/16	. 73	1. 09	1. 44	2. 16	2. 87	4. 36	5. 82	7. 27
. 37	4 7/16	. 77	1. 13	1. 50	2. 25	2. 99	4. 55	6. 06	7. 58
. 38	4 9/16	. 80	1. 18	1. 57	2. 34	3. 11	4. 73	6. 31	7. 89
. 39	4 11/16	. 83	1. 23	1. 63	2. 43	3. 24	4. 92	6. 56	8. 20
. 40	4 13/16	. 87	1. 28	1. 69	2. 53	3. 36	5. 11	6. 81	8. 52
. 41	4 15/16	. 90	1. 32	1. 76	2. 62	3. 49	5. 30	7. 07	8. 84
. 42	5 1/16	. 93	1. 37	1. 82	2. 72	3. 61	5. 50	7. 33	9. 16
. 43	5 3/16	. 97	1. 42	1. 89	2. 81	3. 74	5. 70	7. 59	9. 49
. 44	5 1/4	1. 00	1. 47	1. 95	2. 91	3. 87	5. 90	7. 86	9. 83
. 45	5 3/8	1. 04	1. 53	2. 02	3. 01	4. 01	6. 10	8. 13	10. 2
. 46	5 1/2	1. 07	1. 58	2. 09	3. 11	4. 14	6. 30	8. 40	10. 5
. 47	5 5/8	1. 11	1. 63	2. 16	3. 21	4. 28	6. 51	8. 68	10. 8
. 48	5 3/4	1. 15	1. 68	2. 23	3. 32	4. 41	6. 72	8. 96	11. 2
. 49	5 7/8	1. 18	1. 74	2. 30	3. 42	4. 55	6. 93	9. 24	11. 5
. 50	6	1. 22	1. 79	2. 37	3. 53	4. 69	7. 14	9. 52	11. 9
. 51	6 1/8	1. 26	1. 85	2. 44	3. 64	4. 83	7. 36	9. 81	12. 3
. 52	6 1/4	1. 30	1. 90	2. 51	3. 74	4. 97	7. 57	10. 1	12. 6
. 53	6 3/8	1. 34	1. 96	2. 59	3. 85	5. 12	7. 79	10. 4	13. 0
. 54	6 1/2	1. 38	2. 02	2. 66	3. 96	5. 26	8. 02	10. 7	13. 4
. 55	6 5/8	1. 42	2. 07	2. 74	4. 07	5. 41	8. 24	11. 0	13. 7
. 56	6 3/4	1. 46	2. 13	2. 81	4. 18	5. 56	8. 47	11. 3	14. 1
. 57	6 13/16	1. 50	2. 19	2. 89	4. 30	5. 71	8. 69	11. 6	14. 5
. 58	6 15/16	1. 54	2. 25	2. 97	4. 41	5. 86	8. 92	11. 9	14. 9
. 59	7 1/16	1. 58	2. 31	3. 05	4. 53	6. 01	9. 15	12. 2	15. 3
. 60	7 3/16	1. 62	2. 37	3. 13	4. 64	6. 17	9. 39	12. 5	15. 6
. 61	7 5/16	1. 67	2. 43	3. 20	4. 76	6. 32	9. 62	12. 8	16. 0
. 62	7 7/16	1. 71	2. 49	3. 28	4. 88	6. 47	9. 86	13. 1	16. 4
. 63	7 9/16	1. 75	2. 55	3. 37	5. 00	6. 63	10. 1	13. 5	16. 8
. 64	7 11/16	1. 80	2. 62	3. 45	5. 12	6. 79	10. 3	13. 8	17. 2

Exhibit 3-16 Discharge for Cipolletti weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Chann[illegible], U.S. Dept. Agr. Cir. 843, 1950) (Sheet 1 of 3)

Head, H[1]		Discharge, *Q*, for crest length, *L*, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0. 65	7 13/16	1. 84	2. 68	3. 53	5. 24	6. 95	10. 6	14. 1	17. 6
. 66	7 15/16	1. 89	2. 75	3. 61	5. 36	7. 11	10. 8	14. 4	18. 1
. 67	8 1/16	1. 93	2. 81	3. 70	5. 48	7. 28	11. 1	14. 8	18. 5
. 68	8 3/16	1. 98	2. 87	3. 79	5. 61	7. 44	11. 3	15. 1	18. 9
. 69	8 1/4	2. 02	2. 94	3. 87	5. 73	7. 61	11. 6	15. 4	19. 3
. 70	8 3/8	2. 07	3. 01	3. 95	5. 86	7. 77	11. 8	15. 8	19. 7
. 71	8 1/2	2. 12	3. 07	4. 04	5. 99	7. 94	12. 1	16. 1	20. 1
. 72	8 5/8	2. 16	3. 14	4. 13	6. 12	8. 11	12. 3	16. 5	20. 6
. 73	8 3/4	2. 21	3. 21	4. 22	6. 24	8. 28	12. 6	16. 8	21. 0
. 74	8 7/8	2. 26	3. 28	4. 31	6. 38	8. 45	12. 9	17. 1	21. 4
. 75	9	2. 31	3. 35	4. 40	6. 51	8. 62	13. 1	17. 5	21. 9
. 76	9 1/8	2. 36	3. 42	4. 49	6. 64	8. 80	13. 4	17. 8	22. 3
. 77	9 1/4	2. 41	3. 49	4. 58	6. 77	8. 97	13. 6	18. 2	22. 7
. 78	9 3/8	2. 46	3. 56	4. 67	6. 90	9. 15	13. 9	18. 6	23. 2
. 79	9 1/2	2. 51	3. 63	4. 76	7. 04	9. 33	14. 2	18. 9	23. 6
. 80	9 5/8	2. 56	3. 70	4. 85	7. 18	9. 51	14. 5	19. 3	24. 1
. 81	9 3/4	2. 61	3. 77	4. 95	7. 31	9. 69	14. 7	19. 6	24. 5
. 82	9 13/16	2. 66	3. 84	5. 04	7. 45	9. 87	15. 0	20. 0	25. 0
. 83	9 15/16	2. 71	3. 92	5. 14	7. 59	10. 0	15. 3	20. 4	25. 5
. 84	10 1/16	2. 77	3. 99	5. 23	7. 73	10. 2	15. 6	20. 7	25. 9
. 85	10 3/16	2. 82	4. 07	5. 33	7. 87	10. 4	15. 8	21. 1	26. 4
. 86	10 5/16	2. 87	4. 14	5. 43	8. 01	10. 6	16. 1	21. 5	26. 9
. 87	10 7/16	2. 93	4. 22	5. 52	8. 15	10. 8	16. 4	21. 9	27. 3
. 88	10 9/16	2. 98	4. 29	5. 62	8. 30	11. 0	16. 7	22. 2	27. 8
. 89	10 11/16	3. 04	4. 37	5. 72	8. 44	11. 2	17. 0	22. 6	28. 3
. 90	10 13/16	3. 09	4. 45	5. 82	8. 59	11. 4	17. 2	23. 0	28. 7
. 91	10 15/16	3. 15	4. 53	5. 92	8. 73	11. 6	17. 5	23. 4	29. 2
. 92	11 1/16	3. 20	4. 60	6. 02	8. 88	11. 7	17. 8	23. 8	29. 7
. 93	11 3/16	3. 26	4. 68	6. 13	9. 03	11. 9	18. 1	24. 2	30. 2
. 94	11 1/4	3. 32	4. 76	6. 23	9. 17	12. 1	18. 4	24. 5	30. 7
. 95	11 3/8	3. 37	4. 84	6. 33	9. 32	12. 3	18. 7	24. 9	31. 2
. 96	11 1/2	3. 43	4. 92	6. 44	9. 48	12. 5	19. 0	25. 3	31. 7
. 97	11 5/8	3. 49	5. 00	6. 55	9. 62	12. 7	19. 3	25. 7	32. 2
. 98	11 3/4	3. 55	5. 09	6. 64	9. 78	12. 9	19. 6	26. 1	32. 7
. 99	11 7/8	3. 61	5. 17	6. 75	9. 93	13. 1	19. 9	26. 5	33. 2
1. 00	12	3. 67	5. 25	6. 86	10. 1	13. 3	20. 2	26. 9	33. 7
1. 01	12 1/8	......	5. 33	6. 96	10. 2	13. 5	20. 5	27. 3	34. 2
1. 02	12 1/4	......	5. 42	7. 07	10. 4	13. 7	20. 8	27. 7	34. 7
1. 03	12 3/8	......	5. 50	7. 18	10. 6	13. 9	21. 1	28. 2	35. 2
1. 04	12 1/2	......	5. 59	7. 29	10. 7	14. 2	21. 4	28. 6	35. 7
1. 05	12 5/8	......	5. 67	7. 40	10. 9	14. 4	21. 7	29. 0	36. 2
1. 06	12 3/4	......	5. 76	7. 51	11. 0	14. 6	22. 0	29. 4	36. 7
1. 07	12 13/16	......	5. 84	7. 62	11. 2	14. 8	22. 4	29. 8	37. 3
1. 08	12 15/16	......	5. 93	7. 73	11. 4	15. 0	22. 7	30. 2	37. 8
1. 09	13 1/16	......	6. 02	7. 84	11. 5	15. 2	23. 0	30. 6	38. 3
1. 10	13 3/16	......	6. 11	7. 96	11. 7	15. 4	23. 3	31. 1	38. 8
1. 11	13 5/16	......	6. 20	8. 07	11. 8	15. 6	23. 6	31. 5	39. 4
1. 12	13 7/16	......	6. 29	8. 18	12. 0	15. 8	23. 9	31. 9	39. 9
1. 13	13 9/16	......	6. 38	8. 29	12. 2	16. 0	24. 3	32. 4	40. 4
1. 14	13 11/16	......	6. 47	8. 41	12. 3	16. 3	24. 6	32. 8	41. 0
1. 15	13 13/16	......	6. 56	8. 53	12. 5	16. 5	24. 9	33. 2	41. 5
1. 16	13 15/16	......	6. 65	8. 65	12. 7	16. 7	25. 2	33. 6	42. 1
1. 17	14 1/16	......	6. 74	8. 76	12. 8	16. 9	25. 6	34. 1	42. 6
1. 18	14 3/16	......	6. 83	8. 88	13. 0	17. 2	25. 9	34. 5	43. 2
1. 19	14 1/4	......	6. 93	9. 00	13. 2	17. 4	26. 2	35. 0	43. 7

Exhibit 3-16 Discharge for Cipolletti weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

(Sheet 2 of 3)

Head, H[1]		Discharge, *Q*, for crest length, *L*, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
1.20	14⅜	------	7.02	9.12	13.4	17.6	26.6	35.4	44.3
1.21	14½	------	7.11	9.24	13.5	17.8	26.9	35.8	44.8
1.22	14⅝	------	7.20	9.36	13.7	18.0	27.2	36.3	45.4
1.23	14¾	------	7.30	9.48	13.9	18.3	27.6	36.7	45.9
1.24	14⅞	------	7.40	9.60	14.0	18.5	27.9	37.2	46.5
1.25	15	------	7.49	9.72	14.2	18.7	28.2	37.6	47.1
1.26	15⅛	------	--------	--------	14.4	19.0	28.6	38.1	47.6
1.27	15¼	------	--------	--------	14.6	19.2	28.9	38.5	48.2
1.28	15⅜	------	--------	--------	14.7	19.4	29.3	39.0	48.8
1.29	15½	------	--------	--------	14.9	19.6	29.6	39.5	49.3
1.30	15⅝	------	--------	--------	15.1	19.9	29.9	39.9	49.9
1.31	15¾	------	--------	--------	15.3	20.1	30.3	40.4	50.5
1.32	15 13/16	------	--------	--------	15.5	20.3	30.6	40.8	51.1
1.33	15 15/16	------	--------	--------	15.6	20.6	31.0	41.3	51.6
1.34	16 1/16	------	--------	--------	15.8	20.8	31.3	41.8	52.2
1.35	16 3/16	------	--------	--------	16.0	21.1	31.7	42.2	52.8
1.36	16 5/16	------	--------	--------	16.2	21.3	32.0	42.7	53.4
1.37	16 7/16	------	--------	--------	16.4	21.5	32.4	43.2	54.0
1.38	16 9/16	------	--------	--------	16.6	21.8	32.7	43.7	54.6
1.39	16 11/16	------	--------	--------	16.8	22.0	33.1	44.1	55.2
1.40	16 13/16	------	--------	--------	16.9	22.3	33.5	44.6	55.8
1.41	16 15/16	------	--------	--------	17.1	22.5	33.8	45.1	56.4
1.42	17 1/16	------	--------	--------	17.3	22.8	34.2	45.6	57.0
1.43	17 3/16	------	--------	--------	17.5	23.0	34.6	46.1	57.6
1.44	17¼	------	--------	--------	17.7	23.3	34.9	46.5	58.2
1.45	17⅜	------	--------	--------	17.9	23.5	35.3	47.0	58.8
1.46	17½	------	--------	--------	18.1	23.8	35.6	47.5	59.4
1.47	17⅝	------	--------	--------	18.3	24.0	36.0	48.0	60.0
1.48	17¾	------	--------	--------	18.5	24.3	36.4	48.5	60.6
1.49	17⅞	------	--------	--------	18.7	24.5	36.7	49.0	61.2
1.50	18	------	--------	--------	18.9	24.8	37.1	49.5	61.8

[1] Values of discharge for heads up to 0.20 foot (crest lengths 1, 1.5, 2, 3, and 4 feet) do not follow the formula but are taken directly from the calibration curve. The discharge for heads 0.10 to 1.5 feet for the 6-, 8,- and 10-foot weirs are as computed by the formula $Q=3.367LH^{3/2}$.

Exhibit 3-16 Discharge for Cipolletti weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

(Sheet 3 of 3)

Head, *H*		Discharge, *Q*	Head, *H*		Discharge, *Q*	Head, *H*		Discharge, *Q*
Feet	*Inches*	*Second-feet*	*Feet*	*Inches*	*Second-feet*	*Feet*	*Inches*	*Second-feet*
0.15	1 13/16	0.022	0.55	6 5/8	0.564	0.95	11 3/8	2.19
.16	1 15/16	.025	.56	6 3/4	.590	.96	11 1/2	2.25
.17	2 1/16	.029	.57	6 13/16	.617	.97	11 5/8	2.31
.18	2 3/16	.034	.58	6 15/16	.644	.98	11 3/4	2.37
.19	2 1/4	.040	.59	7 1/16	.672	.99	11 7/8	2.43
.20	2 3/8	.046	.60	7 3/16	.700	1.00	12	2.49
.21	2 1/2	.052	.61	7 5/16	.730	1.01	12 1/8	2.55
.22	2 5/8	.058	.62	7 7/16	.760	1.02	12 1/4	2.61
.23	2 3/4	.065	.63	7 9/16	.790	1.03	12 3/8	2.68
.24	2 7/8	.072	.64	7 11/16	.822	1.04	12 1/2	2.74
.25	3	.080	.65	7 13/16	.854	1.05	12 5/8	2.81
.26	3 1/8	.088	.66	7 15/16	.887	1.06	12 3/4	2.87
.27	3 1/4	.096	.67	8 1/16	.921	1.07	12 13/16	2.94
.28	3 3/8	.105	.68	8 3/16	.955	1.08	12 15/16	3.01
.29	3 1/2	.115	.69	8 1/4	.991	1.09	13 1/16	3.08
.30	3 5/8	.125	.70	8 3/8	1.03	1.10	13 3/16	3.15
.31	3 3/4	.136	.71	8 1/2	1.06	1.11	13 5/16	3.22
.32	3 13/16	.147	.72	8 5/8	1.10	1.12	13 7/16	3.30
.33	3 15/16	.159	.73	8 3/4	1.14	1.13	13 9/16	3.37
.34	4 1/16	.171	.74	8 7/8	1.18	1.14	13 11/16	3.44
.35	4 3/16	.184	.75	9	1.22	1.15	13 13/16	3.52
.36	4 5/16	.197	.76	9 1/8	1.26	1.16	13 15/16	3.59
.37	4 7/16	.211	.77	9 1/4	1.30	1.17	14 1/16	3.67
.38	4 9/16	.225	.78	9 3/8	1.34	1.18	14 3/16	3.75
.39	4 11/16	.240	.79	9 1/2	1.39	1.19	14 1/4	3.83
.40	4 13/16	.256	.80	9 5/8	1.43	1.20	14 3/8	3.91
.41	4 15/16	.272	.81	9 3/4	1.48	1.21	14 1/2	3.99
.42	5 1/16	.289	.82	9 13/16	1.52	1.22	14 5/8	4.07
.43	5 3/16	.306	.83	9 15/16	1.57	1.23	14 3/4	4.16
.44	5 1/4	.324	.84	10 1/16	1.61	1.24	14 7/8	4.24
.45	5 3/8	.343	.85	10 3/16	1.66	1.25	15	4.33
.46	5 1/2	.362	.86	10 5/16	1.71	1.26	15 1/8	4.42
.47	5 5/8	.382	.87	10 7/16	1.76	1.27	15 1/4	4.51
.48	5 3/4	.403	.88	10 9/16	1.81	1.28	15 3/8	4.60
.49	5 7/8	.424	.89	10 11/16	1.86	1.29	15 1/2	4.69
.50	6	.445	.90	10 13/16	1.92	1.30	15 5/8	4.78
.51	6 1/8	.468	.91	10 15/16	1.97	1.31	15 3/4	4.87
.52	6 1/4	.491	.92	11 1/16	2.02	1.32	15 13/16	4.96
.53	6 3/8	.515	.93	11 3/16	2.08	1.33	15 15/16	5.06
.54	6 1/2	.539	.94	11 1/4	2.13	1.34	16 1/16	5.15

Exhibit 3-17 Discharge for 90° v-notch weirs (Ref. Parshall, R.L., Measuring Water in Irrigation Channels, U.S. Dept. Agr. Cir. 843, 1950)

Head (inches)	3-in. orifice		4-in. orifice		5-in. orifice		6-in. orifice		7-in. orifice	8-in. orifice
	4-in. Pipe	6-in. Pipe	6-in. Pipe	8-in. Pipe	6-in. Pipe	8-in. Pipe	8-in. Pipe	10-in. Pipe	10-in. Pipe	10-in. Pipe
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
6	108	82	160	150	305	240	408	345		
8	122	94	185	170	350	280	458	395	600	935
10	133	104	205	190	393	316	508	445	666	1040
12	146	114	225	208	430	346	556	490	728	1120
14	157	123	243	224	465	376	599	530	785	1194
16	167	132	257	238	495	402	636	568	838	1266
18	178	140	271	252	524	426	672	604	887	1336
20	187	148	285	266	548	449	708	636	933	1404
22	197	156	299	279	572	470	744	664	979	1471
24	205	164	310	291	596	488	776	692	1022	1529
26	214	171	323	303	620	504	805	720	1064	1585
28	222	177	335	314	644	520	831	747	1104	1641
30	230	183	346	325	668	536	857	773	1143	1697
32	239	189	357	335	692	552	882	799	1181	1753
34	246	195	369	345	715	568	907	824	1218	1809
36	254	200	380	354	737	584	931	847	1251	1865
38	260	205	390	363	759	600	955	867	1281	
40	266	210	401	371	781	616	979	887	1311	
42	272	214	411	380	800	631	1001	906	1341	
44	278	219	420	388	820	645	1023	925	1371	
46	284	224	429	396	837	659	1045	944	1401	
48	290	229	440	405	855	672	1067	963	1431	
50	296	234	448	413	872	686	1089	982	1461	
52	302	238	457	421	888	700	1110	1000	1491	
54	307	243	465	429	904	714	1130	1018	1520	
56	313	248	472	437	919	727	1150	1036	1548	
58	317	252	480	445	934	739	1170	1052	1574	
60	323	257	489	453	948	751	1190	1068	1598	
62	328	262	496	461	961	763	1209	1084		
64	333	266	504	469	974	775	1227	1099		
66	338	271	513	475	988	787	1245	1113		
68	343	275	520	483	1002	799	1263	1127		
70	349	280	525	491	1016	811	1280	1140		

Exhibit 3-18 Discharge from circular pipe orifices with free discharge (Ref. Layne Well Water Systems, Layne and Bowler, Inc., Memphis, Tenn., 1951)

Jet height (inches)	Diameter of pipe (inches)													
	2	3	4		5		6		8		10		12	
	Std.[2]	Std.	O.D.[3]	Std.	O.D.	Std.	O.D.	Std.	O.D.	Std.	O.D.	Std.	O.D.	Std.
	G.p.m.	G.p.m.	G.p.m.		G.p.m.		G.p.m.		G.p.m.		G.p.m.		G.p.m.	
2.........	28	57	75	86	103	115	137	150	200	215	265	285	330	355
2 1/2.....	31	69	95	108	132	150	182	205	275	290	357	385	450	480
3.........	34	78	112	128	160	183	225	250	340	367	450	490	570	610
3 1/2.....	37	86	124	145	183	210	262	293	405	440	555	610	705	755
4.........	40	92	135	160	205	235	295	330	465	510	660	725	845	910
4 1/2	42	98	144	173	225	257	320	365	520	570	760	845	980	1060
5.........	45	104	154	184	240	275	345	395	575	630	840	940	1120	1200
6.........	50	115	169	205	266	306	385	445	670	730	1000	1125	1370	1500
7.........	54	125	186	223	293	336	420	485	750	820	1150	1275	1600	1730
8.........	58	134	202	239	315	360	450	520	810	890	1270	1420	1775	1950
9.........	62	143	215	254	335	383	480	550	870	955	1360	1550	1930	2140
10........	66	152	227	268	356	405	510	585	925	1015	1450	1650	2070	2280
12........	72	167	255	295	390	450	565	650	1010	1120	1600	1830	2300	2550
14........	78	182	275	320	420	485	610	705	1100	1220	1730	2000	2530	2800
16........	83	195	295	345	455	520	655	755	1180	1300	1870	2140	2720	3000
18........	89	208	315	367	480	555	700	800	1265	1400	2000	2280	2900	
20........	94	220	333	388	510	590	740	850	1335	1480	2100	2420		
25........	107	248	377	440	580	665	830	960	1520	1670	2380	2720		
30........	117	275	420	485	640	740	925	1050	1690	1870	2650	3000		
35........	127	300	455	525	695	800	1000	1150	1820	2020	2850			
40........	137	320	490	565	745	865	1075	1230	1970	2160				

[2] **Standard pipe.**
[3] **Outside diameter of well casing.**

Exhibit 3-19 Flow of water from vertical pipes (Ref. Discharge Curves in Utah Eng. Expt. Sta. Bulletin 5, "Measurement of Irrigation Water," June 1955)

WHEN X = 0

Y (inches)	Size of pipe (nominal diameter)				
	2-inch	3-inch	4-inch	5-inch	6-inch
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
0.20		67.7	180	308	
.30		66.5	175	303	530
.40		65.1	171	298	518
.50		63.6	166	293	506
.60	18.3	62.0	161	287	494
.70	17.6	60.4	156	282	482
.80	16.7	58.4	150	277	470
.90	15.4	55.7	145	271	458
1.00	13.7	53.1	139	265	446
1.20	9.5	46.9	128	251	422
1.40	6.0	40.5	115	237	398
1.60		31.9	102	221	373
1.80		24.0	90	205	347
2.00		17.3	77	187	321
2.20		11.8	64	167	295
2.40		7.3	52	147	270
2.60			41	127	246
2.80			32	108	223
3.00			24	90	200
3.30			13	65	167
3.60				45	137
3.90				29	111
4.20					86
4.50					64
4.80					45

Exhibit 3-20 Flow of water from horizontal pipes (Ref. Purdue Eng. Expt. Bulletin 32, "Measurement of pipe flow by the coordinate method," August 1928)

(Sheet 1 of 3)

WHEN X = 6 INCHES

Y (inches)	Size of pipe (nominal diameter)				
	2-inch	3-inch	4-inch	5-inch	6-inch
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
0.24	177	310	548		
.36	146	274	503	969	1243
.48	126	247	462	857	1113
.60	111	229	435	772	1019
.72	100	215	404	705	947
.84	92	202	377	646	889
.96	85	193	355	606	844
1.08	79	184	337	574	808
1.20	75	175	319	543	772
1.80	60	139	265	449	660
2.40	51	119	229	390	583
3.00	45	105	206	350	525
3.60	40	94	188	314	476
4.20	37	86	169	278	431
4.80	35	79	151	238	386
5.40	32	71	133	193	332
6.00	30	63	116	150	247
6.60	27	50	99	112	
7.20	25	38	83		
7.80	23	29	69		
8.40	20				

WHEN X = 12 INCHES

.96	157	319	570	1014	
1.08	148	305	548	974	1315
1.20	139	292	530	925	1257
1.80	114	247	444	763	1065
2.40	99	215	395	655	929
3.00	87	193	359	583	844
3.60	79	176	332	530	772
4.20	73	161	305	489	718
4.80	68	149	287	458	673
5.40	63	140	269	426	633
6.00	60	132	256	404	597
6.60	57	126	242	386	574
7.20	54	120	233	368	548
7.80	52	114	224	355	525

Exhibit 3-20 **Flow of water from horizontal pipes (Ref. Purdue Eng. Expt. Bulletin 32, "Measurement of pipe flow by the coordinate method," August 1928)**

(Sheet 2 of 3)

WHEN X = 18 INCHES

Y (inches)	Size of pipe (nominal diameter)				
	2-inch	3-inch	4-inch	5-inch	6-inch
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
1.80	166	346	624	1014	1400
2.40	144	305	557	907	1261
3.00	129	274	503	826	1153
3.60	117	251	462	754	1068
4.20	109	233	431	700	992
4.80	101	220	404	655	934
5.40	95	206	382	615	884
6.00	89	197	364	579	839
6.60	84	187	346	548	799
7.20	81	180	332	521	763
7.80	77	172	319	498	732
8.40	75	166	305	476	705

Exhibit 3-20 Flow of water from horizontal pipes (Ref. Purdue Eng. Expt. Bulletin 32, "Measurement of pipe flow by the coordinate method," August 1928) (Sheet 3 of 3)

Chapter 3

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2. Hydraulic Charts for the Selection of Highway Culverts, Hydraulic Engineering Circular No. 5, Bureau of Public Roads, Department of Transportation

3. Hydraulic and Excavation Tables, U. S. Department of Interior, Bureau of Reclamation

4. Hydraulic Tables, U. S. Department of Defense, Corps of Engineers

5. Chow, VenTe; Open-Channel Hydraulics, McGraw-Hill Book Co., Inc., 1959

6. National Engineering Handbook, Section 5, Hydraulics

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b. Utah State Engineering Handbook, Section 5, Hydraulics

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ENGINEERING FIELD MANUAL

CHAPTER 4. ELEMENTARY SOIL ENGINEERING

Compiled by: Clarence E. Dennis, Civil Engineer, SCS, Lincoln, Nebraska

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Nomenclature

D_w = Density of Water (numerically = γ_w)
e = Void Ratio
LL = Liquid Limit
M = Mass or Mass Weight ($M = \frac{W}{32.2}$)
n = Porosity; Percent Voids
PI = Plasticity Index
PL = Plastic Limit
S = Degree of Saturation
SI = Shrinkage Index
SL = Shrinkage Limit
V = Total Volume of a Soil
V_a = Volume of Air
V_s = Volume of Soil Solids
V_v = Volume of Voids
V_w = Volume of Soil Water
V_M = Volume of Mass
W = Total Weight of Soil
W_a = Weight of Air (value usually zero)
W_s = Weight of Soil Solids
W_w = Weight of Soil Water
w = Water Content of Soil -- percent of dry weight
γ = Unit Weight (General Definition)
γ_d = Unit Dry Weight
γ_m = Unit Moist Weight
γ_{sat} = Unit Saturated Weight
γ_w = Unit Weight of Water (numerically same as D_w)
C_u = Coefficient of Uniformity
C_c = Coefficient of Curvature

ENGINEERING FIELD MANUAL

CHAPTER 4. ELEMENTARY SOIL ENGINEERING

1. GENERAL

DEFINITION

Soil Engineering is the application of known physical, chemical and mechanical properties of soil to its use as a primary construction material and as a foundation for structures.

2. BASIC CONCEPTS

SOIL

Soil is defined as sediments which are earth particles: 1) Deposited by running water; 2) deposited in still water; or 3) other accumulations of unconsolidated particles resulting from the physical and chemical disintegration of rocks. Soil may or may not contain organic matter.

Soil, sometimes referred to in engineering as "bulk soil" or "soil mass", consists of the solid soil matter plus the space not occupied by solids. This space is called "soil voids" or simply "voids". Therefore, the term "soil" as commonly used consists of both solids and voids.

SOIL SOLIDS

The composition of mineral soil particles resulting from physical disintegration will remain about the same as the composition of the parent rock or the minerals making up the parent rock. For example, granite often breaks down into individual particles of its minerals: feldspar, quartz and mica.

Chemical action on rocks causes decomposition of the rock. Certain acids or salts and the elements of water and air will, when associated with rock minerals under favorable conditions, combine to form new chemical compounds not present in the parent rock.

Decomposition usually happens after disintegration. The mineral content of the parent rock and how far disintegration and decomposition have progressed determine the kind of soil produced and the engineering properties of that soil.

Soil formed "in place" from parent rock is called residual soil. A large percentage of the earth's soil mass has been transported, often far from its original location in the earth's crust. Soil may be transported by gravity, water and wind.

Gravity transportation may be slow and almost unnoticed or it may be rapid. Examples are loosened particles that roll or slide down a steep slope; glaciers that gouge out soil at one place and drop it at another; and large masses of earth that slowly "creep" in a downhill direction. Landslides are often violent and spectacular.

Water and wind transportation have two common characteristics. Each transports soil particles by rolling or sliding the particles along the ground surface or by picking particles up and carrying them in suspension. Each tends to separate and deposit particles according to their size.

Transportation processes are important agents of disintegration, particularly in producing very fine particles by wearing away larger particles. Except for residual soils, the kind of soil and its engineering properties are partially the result of how it was transported and deposited.

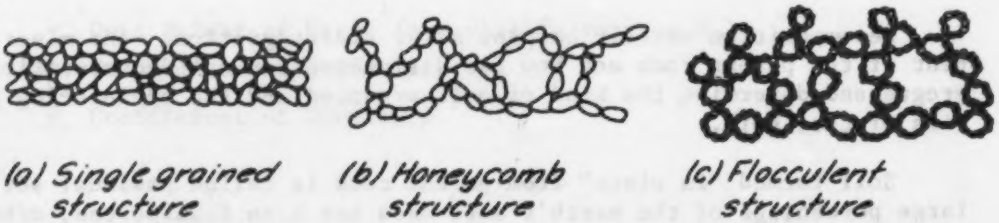
The sizes of the granular soil particles depend on the ease with which the parent rock is disintegrated and decomposed and the length of time these processes have had time to act. The shapes of granular particles are described as:

1. Angular - containing sharp edges and points characteristic of newly formed particles.
2. Sub-angular, sub-rounded or rounded - characteristics of older particles with the sharp edges and rough surfaces worn away or smoothed off.

The size and shape of clay particles are determined by the chemical composition and molecular structure of each particular kind of clay.

SOIL STRUCTURE

Soil structure is defined as the arrangement and grouping of soil particles in a soil mass. "Flocculent structure" describes soil held together in groups or clusters of individual soil particles called "flocs." See Figure 4-1.


(a) Single grained structure

(b) Honeycomb structure

(c) Flocculent structure

Figure 4-1 Types of soil structure of foundation soils

When not flocculated, the soil particles are said to be dispersed and the soil is called "single-grain" structure. Single-grain structure is characteristic of coarse-grained or granular soils.

"Honeycomb structure" describes an arrangement of soil particles that is relatively loose (open) but stable, somewhat resembling honeycomb in appearance.

SOIL VOIDS

Soil voids are that portion of a soil volume not occupied by solids. In a natural state, the voids may be filled by liquid or gas or both.

Gas occupying the voids is usually air. In soil engineering, voids air is treated as weightless. Liquid occupying the voids usually is water. Water contained in the voids is considered as incompressible in soil engineering.

MOISTURE IN SOIL

The moisture in a soil may be described as:

1. The ratio of the volume of water in the voids to the total volume of the voids.

2. The weight of the water in the voids to the weight of the dry soil particles.

The optimum moisture content is the percentage of moisture in a soil, based on its dry weight, at which the maximum density is obtained under a given compactive effort.

Saturated soil has its voids completely filled with water. An example would be soil below the water table.

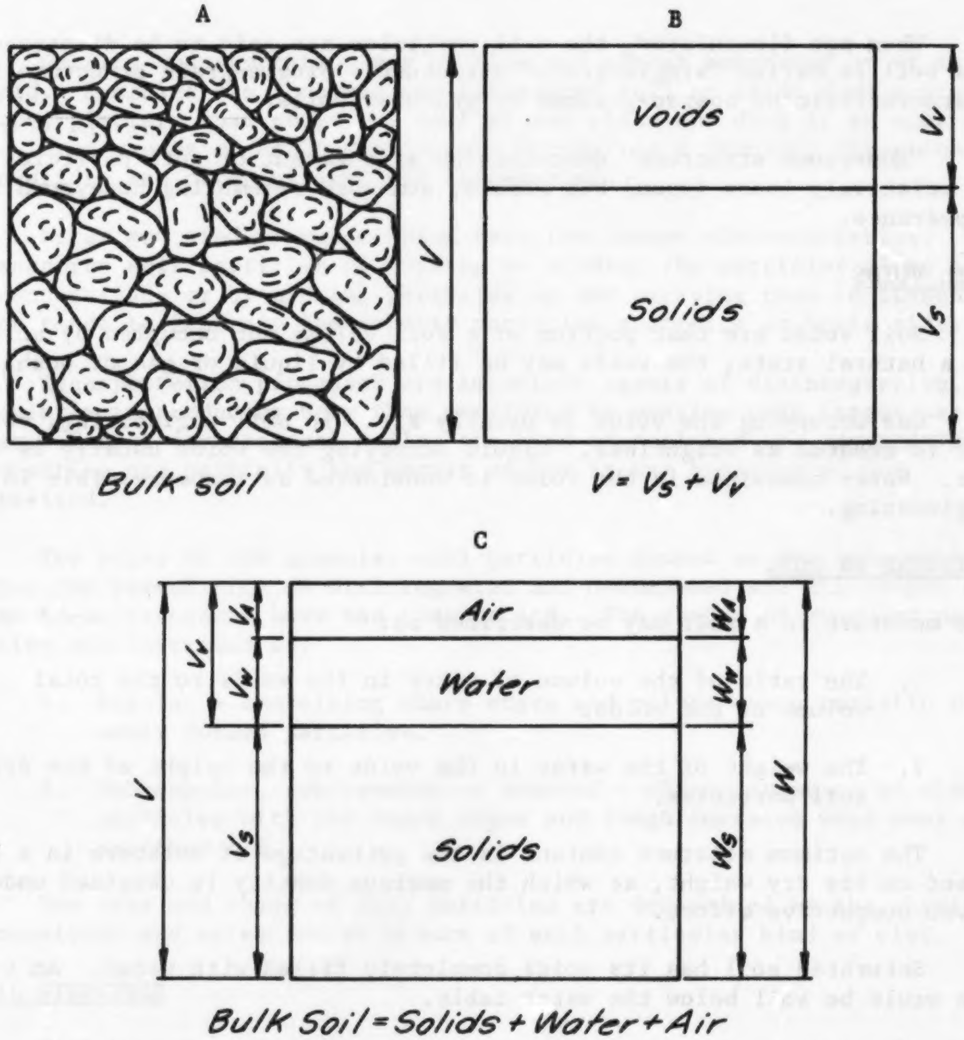
Wet soil requires drying to attain optimum moisture content.

Moist soil contains water very near optimum moisture content.

Dry soil contains only air in the voids (water has been removed by heating to 110° ± 5°C. to constant weight). Soils in this condition require the addition of considerable water to obtain optimum moisture content for standard compaction.

Saturated and dry conditions usually represent definite moisture contents while moist and wet conditions are general ranges between these two.

All bulk soils, as used in soil engineering, are composed of solids plus air or water or both air and water. In the remainder of this discussion the term "soil" will be used broadly to include solids, water and air.


A
B
Voids
Solids
V
Vv
Vs
Bulk soil
V = Vs + Vv
C
Air
Water
Solids
Va
Vv
Vw
V
Vs
Ww
W
Ws
Bulk Soil = Solids + Water + Air

Volumes

$V = V_s + V_w + V_a$

$V_v = V_a + V_w$

Void Ratio, $e = \dfrac{V_v}{V_s}$

Porosity, $n = \dfrac{V_v}{V}$

Percent Saturation, $S = \dfrac{V_w}{V_v} \times 100\ (\%)$

Weights

$W = W_s + W_w + (W_a = 0)$

Percent Moisture,

$w = \dfrac{W_w}{W_s} \times 100\ (\%)$

Figure 4-2 Basic concepts of soil volume and weight

VOLUME RELATIONSHIPS

Figure 4-2 (sketch 1) represents a definite volume of soil composed of solids and voids. Figure 4-2 (sketch 2) represents the same soil with the solids and voids volumes separated into their respective proportions. The total volume is always equal to the sum of the volumes of the solids and the voids.

$$V = V_s + V_v$$

Figure 4-2 (sketch 3) represents the same soil volume with some water added but not enough to completely fill the voids. The soil is now composed of solids, water and air. In this state, the volume of the voids is equal to the sum of the volumes of water and air.

$$V_v = V_w + V_a$$

The total volume is equal to the sum of the volumes of the solids, water and air.

$$V = V_s + V_w + V_a$$

VOLUME RATIOS

Certain volume ratios have been found to be useful in soil engineering.

Void Ratio

Void ratio "e" is the ratio of the volume of the voids to the volume of the solids.

$$e = \frac{V_v}{V_s} \qquad \text{(dimensionless)}$$

The void ratio value can be equal to, greater than, or less than one.

Porosity Ratio

Porosity "n" is the ratio of the volume of voids to the total volume.

$$n = \frac{V_v}{V} \qquad \text{(dimensionless)}$$

Numerically, porosity can never be greater than one.

The equation $n = \frac{V_v}{V} \times 100$ expresses the volume of voids as a percentage of the total volume. When so expressed, it is called "percent voids."

Degree of Saturation

Degree of saturation "S" is the ratio of the volume of water in the voids to the volume of the voids.

$$S = \frac{V_w}{V_v} \qquad \text{(dimensionless)}$$

Numerically, the degree of saturation cannot be greater than one. When the equation is changed to $S = \frac{V_w}{V_v} \times 100$, the expression becomes "percent saturation." It expresses the water volume as a percentage of the total volume of the voids. When the voids are completely filled with water, $V_w = V_v$, and the percent saturation equals 100 percent.

WEIGHT RELATIONSHIPS

Figure 4-2 (sketch 3) points out that the total weight is equal to the sum of the weights of the solids, water and air.

$$W = W_s + W_w + W_a$$

or $W = W_s + W_w$ since the weight of the air is considered to be zero.

PERCENT MOISTURE

An important weight ratio in soils engineering is the ratio of the weight of the water in the soil to the weight of the solids. This ratio multiplied by 100 is the moisture content in percent.

$$w = \frac{W_w}{W_s} \times 100 = \text{Percent moisture}$$

UNIT WEIGHT AND DENSITY

Unit weight γ, is defined as weight per unit volume. For a soil mass, at any moisture state, of total weight W, and total volume V, its unit weight γ is:

$$\gamma = \frac{W}{V}$$

Units of unit weight must be consistent with the units of W and V.

$$\text{British unit system, } \gamma = \frac{W(\text{lbs.})}{V(\text{cu.ft.})} = \text{lbs./cu.ft.,(p.c.f.)}$$

$$\text{Metric unit system, } \gamma = \frac{W(\text{gm})}{V(\text{cm})^3} = \text{gm/cm}^3\text{, or gm/cc}$$

Although not strictly true, density and unit weight are used interchangeably in soil engineering and are both represented by γ.

The mass of one cubic centimeter of distilled water at 4°C. is 1.0 gram. Therefore, the density of distilled water at 4°C. is:

$$\gamma_w = \frac{1\ (\text{gm})}{1\ (\text{cc})} = 1.0\ \text{gm/cc}$$

in the metric system of units.

Since 1.0 gm = .002205 lbs. and
1.0 cc = .00003531 cu.ft.

$$\gamma_w = \frac{1.0 \times .002205}{1.0 \times .00003531} \text{ lbs./cu.ft.}$$

$$\therefore \gamma_w = 62.4 \text{ p.c.f. in the British unit system}$$

The unit weight of soil at each of three most used moisture contents have standard subscripts. They may be written as follows:

$$\text{Unit dry weight, } \gamma_d = \frac{W_s}{V}, \text{ where } V_w = 0$$

$$\text{Unit moist weight, } \gamma_m = \frac{W_s + W_w + W_a}{V}, \text{ where } W_a = 0$$

$$\text{Unit saturated weight, } \gamma_{sat.} = \frac{W_s + W_w}{V}, \text{ where } V_a = 0$$

BEHAVIOR CHARACTERISTICS

Fine-grained or fine-textured soils possess unique characteristics which are important to their engineering properties. These behavior characteristics are either physical, chemical, or a combination of physical and chemical.

Plasticity is a physical characteristic defined as the property of a soil which allows it to be deformed beyond the point of recovery without cracking or appreciable volume change.

Plasticity also is a soil property. This property is recognized by the soil's behavior known as ease of moldability. A soil is either plastic and moldable or nonplastic and not moldable. All plastic soils are fine-textured but all fine-textured soils are not plastic. A soil composed of finely divided quartz (rock flour) is nonplastic while a clay soil of comparable particle size may be plastic and moldable. Mixtures of such soils will display a degree of plasticity somewhere between plastic and nonplastic.

The moisture content of a plastic soil affects its consistency or relative moldability. Consistency is defined as the relative ease with which a soil can be deformed.

Degrees of consistency are described by the terms hard, very stiff, stiff, firm (medium) and soft. Continue to add water to a dry plastic soil and the mixture will eventually have all the characteristics of a liquid. In changing from a solid to a liquid, the material first becomes a semisolid and then plastic. A Swedish scientist, named Atterberg, developed tests to determine the moisture content at which these changes take place. They are known as the Atterberg limits.

Table 4-1 Identification of consistency of fine-grained soils

Consistency	Identification Procedure	Shear Strength tons/ ft^2 or kg/cm^2
Soft	Easily pentrated several inches by thumb	Less than 0.25
Firm(medium)	Penetrated several inches by thumb with moderate effort	0.25 to 0.50
Stiff	Readily indented by thumb, but penetrated only with great effort	0.50 to 1.00
Very stiff	Readily indented by thumb nail	1.00 to 2.00
Hard	Indented with difficulty by thumbnail	over 2.00

ATTERBERG LIMITS

Although fines are measured as the percentage passing the #200 sieve, Atterberg limits are measured for materials passing the #40 sieve. This apparent inconsistency occurs because Atterberg limits were established and measured on materials passing the #40 sieve many years before the #200 sieve was established as the largest size for fines.

Shrinkage Limit (SL)

The shrinkage limit is the maximum water content at which a reduction in water content will not cause a decrease in the volume of the soil mass. This defines the arbitrary limit between the solid and semisolid states.

Plastic Limit (PL)

The plastic limit is the water content corresponding to an arbitrary limit between the plastic and semisolid states of consistency of a soil. This is the water content at which a soil will just begin to crumble when rolled into a thread approximately 1/8 inch in diameter.

Liquid Limit (LL)

The liquid limit is the water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil. This is the water content at which a pat of soil, cut by a groove of standard dimensions, will flow together for a distance of 1/2 inch under the impact of 25 blows in a standard liquid limit apparatus.

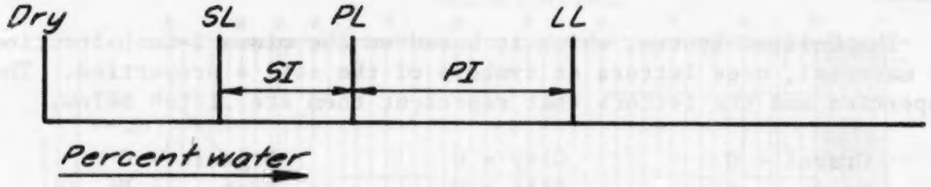


Figure 4-3 Atterberg limits

Refer to Figure 4-3. In the determination of these limits, water is gradually added to that portion of dry soil material that passes the #40 sieve.

At the point the soil becomes plastic, the weight of the water in percent of the dry weight of the soil is known as the plastic limit (PL).

If water is added above the plastic limit, the soil will become liquid. At the point the soil becomes liquid, the weight of the water in percent of the dry weight of the soil is known as the Liquid Limit (LL). The difference between these two values is the water range in which the soil stays plastic and is called the Plasticity Index (PI). In practice, the percent sign is dropped when referring to numerical values of the Atterberg Limits. A material with a liquid limit of 50 percent is referred to as a LL of 50.

Plasticity Index (PI)

The plasticity index is the numerical difference between the liquid limit and plastic limit.

$$PI = LL - PL$$

Shrinkage Index (SI)

The shrinkage index is defined as the numerical difference between the plastic and shrinkage limits.

$$SI = PL - SL$$

3. THE UNIFIED SOIL CLASSIFICATION SYSTEM

GENERAL

The Unified Soil Classification System is used by the Soil Conservation Service in classifying soils for engineering purposes. This system is based on the identification of soils according to their particle size, gradation, plasticity index and liquid limit. (ASTM D 2487, D 2488). Gradation and particle size are determined by sieve analyses. Plastic and liquid limits are determined by standard methods of laboratory testing. (ASTM D 423 and D 424).

SYMBOLS

The Unified System, which is based on the minus 3-inch fraction of the material, uses letters as symbols of the soil's properties. The soil properties and the letters that represent them are listed below.

Gravel - G
Sand - S
Clay - C
Silt - M
Organic - O
Peat - Pt

Well Graded - W
Poorly Graded - P
High Liquid Limit - H
Low Liquid Limit - L

Soils are placed in groups having similar engineering properties according to their behavior characteristics. Each group is delineated by two of the above characteristics. The most important engineering characteristic of this group is listed first and the next most important, second.

U. S. sieve sizes are used in separating some classes of materials from others. The important sieves and the size of their openings are:

Table 4-2 Sieve sizes and size of openings

U. S. Standard Sieve Sizes	Size of Opening in mm.	Size of Opening in inches
3"	--	3"
3/4"	--	3/4"
#4	4.76	1/4" (Approx.)
#10	2.00	--
#40	0.42	--
#200	0.074	--

BASIC MATERIAL BREAKDOWN

Soils are divided into coarse materials or fine materials by the #200 sieve. If more than 50 percent of the material, by dry weight, is larger than the #200 sieve, it is a coarse material. If 50 percent or more will pass the #200 sieve, it is a fine material.

Coarse Materials

Coarse material is subdivided into sand and gravel by the #4 sieve. If 50 percent or more of the coarse portion of the material by dry weight is retained on the #4 sieve, the material is classified as a gravel. If more than 50 percent passes the #4 sieve, it is classified as a sand.

Materials With Less Than 5 Percent Fines

If less than 5 percent of the total sample by dry weight is fines, there is not enough of these fines to affect its engineering properties. In this case, only the characteristics of the coarse portion are important

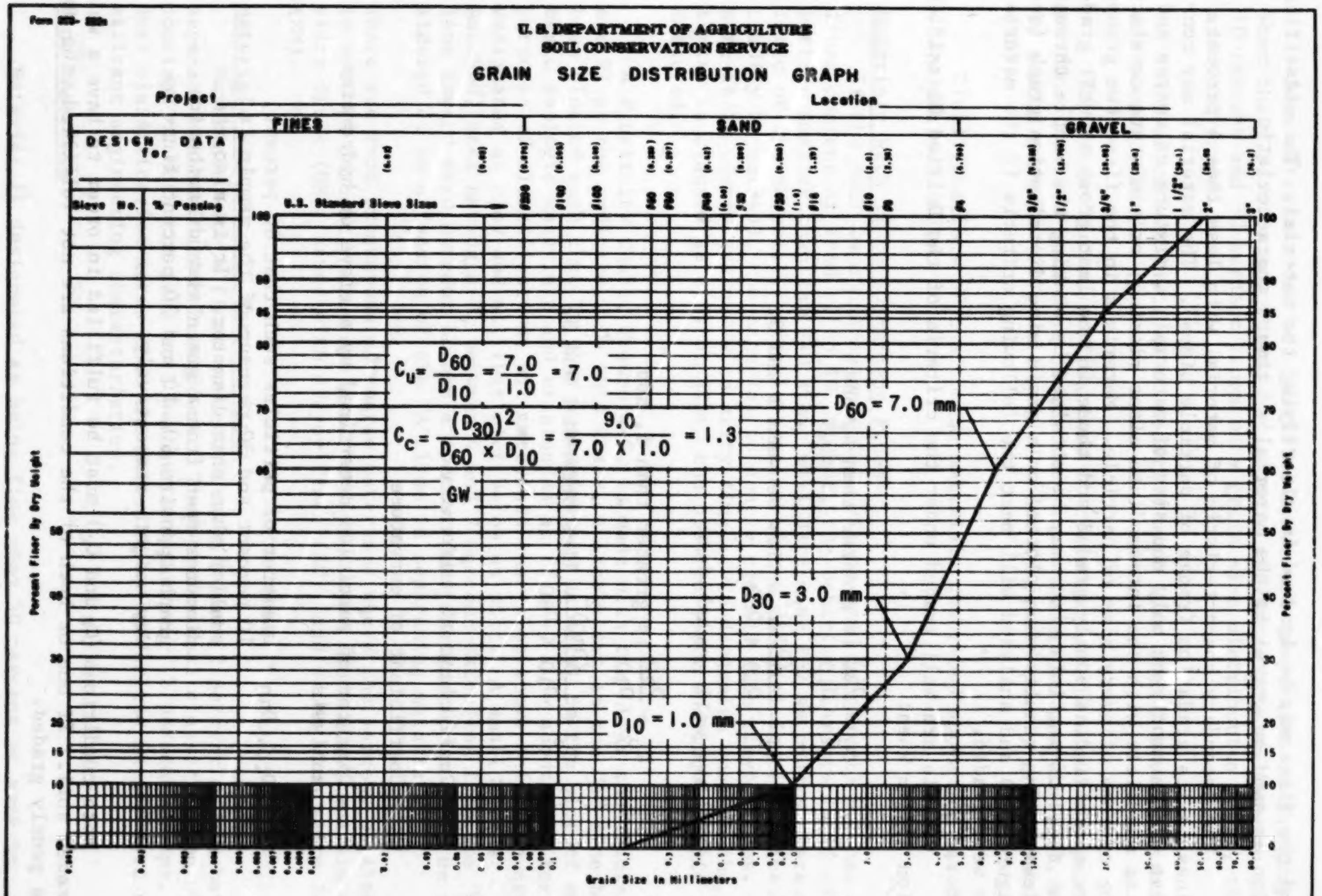


Figure 4-4 D_{60}, D_{30}, D_{10} designation

Sheet No.___ of___

and the fines may be ignored in classifying the material. The classification as sand or gravel is the material's primary characteristic.

The secondary characteristic of material with less than 5 percent fines is its gradation (range of particle sizes). The material may consist predominantly of only one size of material; a mixture of coarse and fine materials with the intermediate sizes missing; or a mixture consisting of some of every size of particle. Materials in the first two groups are classified as poorly graded and those in the last group as well graded. The range of particle sizes may be obtained by shaking the sample through sieves. The results when plotted on a grain size distribution graph (see Figure 4-4) and analyzed will meet the following criteria if the material is well graded.

Gravels are well graded under the criteria of the Unified Classification System when:

$$C_u = \frac{D_{60}}{D_{10}} \text{ is greater than 4, and}$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \text{ lies between 1 and 3.}$$

Sand are well graded when:

$$C_u = \frac{D_{60}}{D_{10}} \text{ is greater than 6, and}$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \text{ lies between 1 and 3.}$$

Where:

C_u = Coefficient of uniformity

C_c = Coefficient of curvature

D = Diameter of particles determined by a sieve or hydrometer analysis

D_{60}, D_{10}, D_{30} = Diameter of particles such that 60 percent, 10 percent and 30 percent of the sample is smaller than that diameter. It is also the diameter read from a grain size distribution graph opposite 60, 10 and 30 percent finer by dry weight, respectively.

Both conditions (C_u and C_c) must be fulfilled in order to have a well graded soil. If one or both of the conditions are not fulfilled, the soil is poorly graded.

Some materials can be classified by visual inspection of the graph. When their plot is smooth and has concave curvature upwards between the 10 percent and 60 percent lines on a grain size distribution graph, they are well graded.

All other combinations of material with less than 5 percent fines are poorly graded.

There are four classifications of coarse materials where the percent of fines is less than 5 percent. They are well graded gravels (GW), poorly graded gravels (GP), well graded sands (SW), and poorly graded sands (SP).

Classifications of the coarse materials described above are based on sieve analysis only.

Materials With 12 to 50 Percent Fines

If the soil is a coarse material (either sand or gravel) but has a fines content of from 12 to 50 percent, the behavior characteristic of the portion smaller than the #40 sieve will determine the secondary characteristic of the material. If this portion of the material is clayey (can readily be molded), the material is coarse grained with clayey fines. If not, it is coarse grained with silty fines. To determine whether the material is classed as clay or silt, the plastic limit and liquid limit are measured.

A Plasticity Chart, Figure 4-5, is made with the LL as the abscissa and PI as the ordinate. On this chart, a line known as the "A" line has been plotted such that it lies approximately parallel to the plot of many basic geologic materials and originates at PI = 4, LL = about 25. For purposes of classification, all materials that plot above this line are designated as clay and all that plot below as silt. A small (cross hatched) area having a PI between 4 and 7 percent extending from the "A" line toward zero percent LL has a special dual designation and may be considered as an extension of the "A" line in separating materials.

There are four breakdowns of coarse materials where the percent of fines is over 12 percent. They are gravels with clayey fines (GC), gravels with silty fines (GM), sands with clayey fines (SC), and sands with silty fines (SM).

Materials With 5 to 12 Percent Fines

Materials with a fines content between 5 and 12 percent do not have separate classification breakdowns. They have a dual classification which consists of both the zero to 5 percent and the over 12 percent groups. The dual classification means that the material is borderline in its most significant engineering characteristics.

Fine Materials

Material is designated as being fine when 50 percent or more by weight passes the #200 sieve.

Clay or Silt

Plasticity is the most important engineering property of a fine grained soil. Therefore a fine grained material is classified first according to its plasticity.

The plasticity of the fine grained soils is determined on that portion of the soil which passes the #40 sieve. The material whose plot of the liquid limit and plasticity index falls above the "A" line (Figure 4-5) is classed as a fine grained clayey material. If it plots below the "A" line the material is classed as a fine grained silty material.

Under the Unified Classification System, "clay" or "clayey" is designated as any material that plots above the "A" line. "Silt" or "silty" is any material that plots below the "A" line. The break is the "A" line and is based on the PI.

High or Low Liquid Limit

The second most important characteristic in classifying fine grained material is its liquid limit.

Soil that has a liquid limit over 50 has a high liquid limit and may be either a clayey or silty high liquid limit material. Soil that has a liquid limit less than 50 has a low liquid limit and may be either a clayey or silty low liquid limit material.

There are four breakdowns of fine grained materials: Clayey material with low liquid limit (CL), clayey material with high liquid limit (CH), silty material with low liquid limit (ML) and silty material with high liquid limit (MH).

Organic Material

Materials containing a large percent of organic matter usually can be identified by their color and odor. The characteristics of organic materials are such that they have no easily definable boundaries. They are poor construction materials and need special consultation from an engineer, if used in construction. Some of these materials can be designated as organics of high liquid limit and organics of low liquid limit when tested by a laboratory. Fibrous organics that do not lend themselves even to laboratory tests are called peats. There are three breakdowns of organics: Organics with high liquid limit (OH), organics with low liquid limits (OL) and peats (Pt).

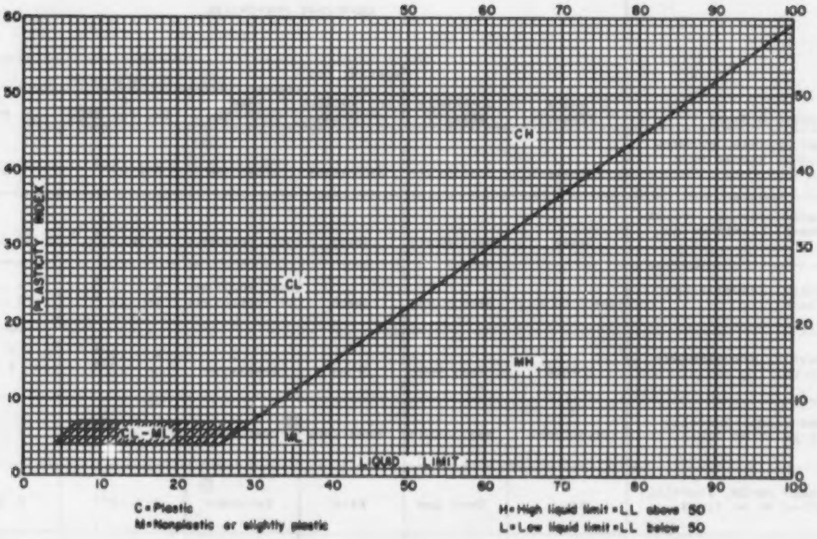


Figure 4-5 Plasticity chart

SUMMARY

Figure 4-6 gives the basic outline of the Unified Classification System.

The Unified Classification System has several outstanding features:

1. It is simple. There are 12 materials with which techicians are normally concerned--four coarse grained materials, four fine grained materials and four combined materials. In addition, there are three organics that require special attention, 15 in all.

2. It provides important physical characteristics, such as size, gradation, plasticity, strength, brittleness, consolidation potential, etc.

3. It is reliable. Engineering properties inferred by the classification are realistic.

	IMPORTANT PROPERTIES						UNIFIED SOIL CLASSES
				PERMEABILITY			
TYPICAL NAMES	SHEAR STRENGTH	COMPRESS-IBILITY	WORKABILITY AS CONSTRUCTION MATERIAL	WHEN COMPACTED	K CM. PER SEC.	K FT. PER DAY	
Well graded gravels, gravel-sand mixtures, little or no fines.	Excellent	Negligible	Excellent	Pervious	K $> 10^{-2}$	K > 30	**GW**
Poorly graded gravels, gravel-sand mixtures, little or no fines.	Good	Negligible	Good	Very Pervious	K $> 10^{-2}$	K > 30	**GP**
Silty gravels, gravel-sand-silt mixtures.	Good to Fair	Negligible	Good	Semi-Pervious to Impervious	K $= 10^{-3}$ to 10^{-6}	K $= 3$ to 3×10^{-3}	**GM**
Clayey gravels, gravel-sand-clay mixtures.	Good	Very Low	Good	Impervious	K $= 10^{-6}$ to 10^{-8}	K $= 3 \times 10^{-3}$ to 3×10^{-5}	**GC**
Well graded sands, gravelly sands, little or no fines.	Excellent	Negligible	Excellent	Pervious	K $> 10^{-3}$	K > 3	**SW**
Poorly graded sands, gravelly sands, little or no fines.	Good	Very Low	Fair	Pervious	K $> 10^{-3}$	K > 3	**SP**
Silty sands, sand-silt mixtures	Good to Fair	Low	Fair	Semi-Pervious to Impervious	K $= 10^{-3}$ to 10^{-6}	K $= 3$ to 3×10^{-3}	**SM**
Clayey sands, sand-clay mixtures.	Good to Fair	Low	Good	Impervious	K $= 10^{-6}$ to 10^{-8}	K $= 3 \times 10^{-3}$ to 3×10^{-5}	**SC**
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	Fair	Medium to High	Fair	Semi-Pervious to Impervious	K $= 10^{-3}$ to 10^{-6}	K $= 3$ to 3×10^{-3}	**ML**
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Fair	Medium	Good to Fair	Impervious	K $= 10^{-6}$ to 10^{-8}	K $= 3 \times 10^{-3}$ to 3×10^{-5}	**CL**
Organic silts and organic silty clays of low plasticity.	Poor	Medium	Fair	Semi-Pervious to Impervious	K $= 10^{-4}$ to 10^{-6}	K $= 3 \times 10^{-1}$ to 3×10^{-3}	**OL**
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Fair to Poor	High	Poor	Semi-Pervious to Impervious	K $= 10^{-4}$ to 10^{-6}	K $= 3 \times 10^{-1}$ to 3×10^{-3}	**MH**
Inorganic clays of high plasticity, fat clays.	Poor	High to Very High	Poor	Impervious	K $= 10^{-6}$ to 10^{-8}	K $= 3 \times 10^{-3}$ to 3×10^{-5}	**CH**
Organic clays of medium to high plasticity, organic silts.	Poor	High	Poor	Impervious	K $= 10^{-6}$ to 10^{-8}	K $= 3 \times 10^{-3}$ to 3×10^{-5}	**OH**
Peat and other highly organic soils.	NOT SUITABLE FOR CONSTRUCTION						**Pt**

SHEET 1 OF 4

Figure 4-6 Unified classification and properties of soils

EMBANKMENTS								UNIFIED SOIL CLASSES
COMPACTION CHARACTER-ISTICS	STANDARD PROCTER UNIT DENSITY LBS. PER CU. FT.	TYPE OF ROLLER DESIRABLE	RELATIVE CHARACTERISTICS		RESISTANCE TO PIPING	ABILITY TO TAKE PLASTIC DEFORMATION UNDER LOAD WITHOUT SHEARING	GENERAL DESCRIPTION & USE	
			PERME-ABILITY	COMPRESS-IBILITY				
Good	125-135	crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Very stable, pervious shells of dikes and dams.	**GW**
Good	115-125	crawler tractor or steel wheeled & vibratory	High	Very Slight	Good	None	Reasonably stable, pervious shells of dikes and dams.	**GP**
Good with close control	120-135	rubber-tired or sheepsfoot	Medium	Slight	Poor	Poor	Reasonably stable, not well suited to shells but may be used for \impervious cores or blankets.	**GM**
Good	115-130	sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, may be used for impervious core.	**GC**
Good	110-130	crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair	None	Very stable, pervious sections, slope protection required.	**SW**
Good	100-120	crawler tractor & vibratory or steel wheeled	High	Very Slight	Fair to Poor	None	Reasonably stable, may be used in dike with flat slopes.	**SP**
Good with close control	110-125	rubber-tired or sheepsfoot	Medium	Slight	Poor to Very Poor	Poor	Fairly stable, not well suited to shells, but may be used for impervious cores or dikes.	**SM**
Good	105-125	sheepsfoot or rubber-tired	Low	Slight	Good	Fair	Fairly stable, use for impervious core for flood control structures.	**SC**
Good to Poor Close control essential	95-120	sheepsfoot	Medium	Medium	Poor to Very Poor	*Very Poor	Poor stability, may be used for embankments with proper control. *Varies with water content.	**ML**
Fair to Good	95-120	sheepsfoot	Low	Medium	Good to Fair	Good to Poor	Stable, impervious cores and blankets.	**CL**
Fair to Poor	80-100	sheepsfoot	Medium to Low	Medium to High	Good to Poor	Fair	Not suitable for embankments.	**OL**
Poor to Very Poor	70-95	sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction.	**MH**
Fair to Poor	75-105	sheepsfoot	Low	High	Excellent	Excellent	Fair stability with flat slopes, thin cores, blanket & dike sections.	**CH**
Poor to Very Poor	65-100	sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Not suitable for embankments.	**OH**
DO NOT USE FOR EMBANKMENT CONSTRUCTION								**Pt**

SHEET 2 OF 4

Figure 4-6 Unified classification and properties of soils

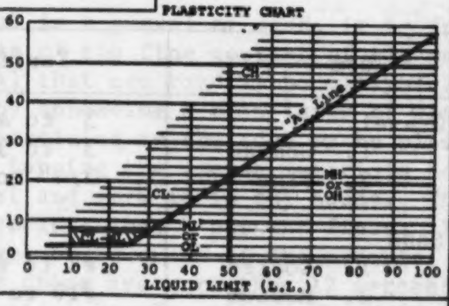
TENTATIVE
FOR TRIAL USE ONLY

CHANNELS LONG DURATION TO CONSTANT FLOWS.		FOUNDATION FOUNDATION SOILS, BEING UNDISTURBED, ARE INFLUENCED TO A GREAT DEGREE BY THEIR GEOLOGIC ORIGIN. JUDGEMENT AND TESTING MUST BE USED IN ADDITION TO THESE GENERALIZATIONS.					UNIFIED SOIL CLASSES
RELATIVE DESIRABILITY			RELATIVE DESIRABILITY		REQUIREMENTS FOR SEEPAGE CONTROL		
EROSION RESISTANCE	COMPACTED EARTH LINING	BEARING VALUE	SEEPAGE IMPORTANT	SEEPAGE NOT IMPORTANT	PERMANENT RESERVOIR	FLOODWATER RETARDING	
1	-	Good	-	1	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GW
2	-	Good	-	3	Positive cutoff or blanket	Control only within volume acceptable plus pressure relief if required.	GP
4	4	Good	2	4	Core trench to none	None	GM
3	1	Good	1	6	None	None	GC
6	-	Good	-	2	Positive cutoff or upstream blanket & toe drains or wells.	Control only within volume acceptable plus pressure relief if required.	SW
7 if gravelly	-	Good to Poor depending upon density	-	5	Positive cutoff or upstream blanket & toe drains or wells.	Control only within volume acceptable plus pressure relief if required	SP
8 if gravelly	5 erosion critical	Good to Poor depending upon density	4	7	Upstream blanket & toe drains or wells	Sufficient control to prevent dangerous seepage piping.	SM
5	2	Good to Poor	3	8	None	None	SC
-	6 erosion critical	Very Poor, susceptible to liquefication	6, if saturated or pre-wetted	9	Positive cutoff or upstream blanket & toe drains or wells.	Sufficient control to prevent dangerous seepage piping.	ML
9	3	Good to Poor	5	10	None	None	CL
-	7 erosion critical	Fair to Poor, may have excessive settlement	7	11	None	None	OL
-	-	Poor	8	12	None	None	MH
10	8 volume change critical	Fair to Poor	9	13	None	None	CH
-	-	Very Poor	10	14	None	None	OH
-	-	REMOVE FROM FOUNDATION					Pt

No. 1 is best numerical rating.

SHEET 3 OF 4

Figure 4-6 Unified classification and properties of soils

				LABORATORY CRITERIA		UNIFIED SOIL CLASSES
COARSE-GRAINED SOILS Less than half of material passes the No. 200 sieve size.	GRAVELS Less than half of the coarse fraction passes the No. 4 sieve size.	CLEAN GRAVELS Less than 5% passing the No. 200 sieve size.	Borderline cases require the use of dual symbols.	WELL GRADED Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 4$ and, $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 & 3	GW
				POORLY GRADED Does not meet gradation requirements		GP
		GRAVELS WITH FINES More than 12% passing the No. 200 sieve size.		Plasticity limits of material passing No. 40 sieve size plots below "A" line or P.I. less than 4.	Plasticity limits above "A" line with P.I. between 4 and 7 are border-line cases and require use of dual symbols	GM
				Plasticity limits of material passing No. 40 sieve size plots above "A" line with P.I. more than 7.		GC
	SANDS More than half of the coarse fraction passes the No. 4 sieve size.	CLEAN SANDS Less than 5% passing the No. 200 sieve size.	Borderline cases require the use of dual symbols.	WELL GRADED Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 6$ and, $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 & 3	SW
				POORLY GRADED Does not meet gradation requirements		SP
		SANDS WITH FINES More than 12% passing the No. 200 sieve size.		Plasticity limits of material passing No. 40 sieve size plots below "A" line or P.I. less than 4.	Plasticity limits above "A" line with P.I. between 4 and 7 are border-line cases and require use of dual symbols	SM
				Plasticity limits of material passing No. 40 sieve size plots above "A" line with P.I. more than 7.		SC
FINE-GRAINED SOILS More than half of material passes the No. 200 sieve size.	SILTS AND CLAYS Liquid limit less than 50	Below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols			ML
		Above "A" line with P.I. more than 7				CL
		Below "A" line or P.I. less than 4 and $\frac{\text{L.L.(oven dry soil)}}{\text{L.L.(air dry soil)}} < 0.7$				OL
	SILTS AND CLAYS Liquid limit greater than 50	Below "A" line				MH
		Above "A" line				CH
		Below "A" line and $\frac{\text{L.L.(oven dry soil)}}{\text{L.L.(air dry soil)}} < 0.7$				OH
HIGHLY ORGANIC SOILS				$\frac{\text{L.L. (oven dry soil)}}{\text{L.L. (air dry soil)}} < 0.7$		Pt

SHEET 4 OF 4

Figure 4-6 Unified classification and properties of soils

4. FIELD IDENTIFICATION OF SOILS

GENERAL

It is desirable to make a field identification of soils and to classify them without the use of special equipment. Soils should be described according to their color, texture and consistency and, where pertinent, their moisture content measured and recorded. Note should be made of the shape, size and gradation of coarse grained soils. The soil should then be classified according to the Unified Soil Classification System.

The classification of a soil should be made using several different field tests rather than a single test. Screening and weighing of samples is not intended. Estimates of percentages of materials by dry weight may be made using visual and finger techniques. With the exception of grain size and gradation, these tests are performed on that portion of the sample smaller than the #40 sieve. When coarse materials that can be separated by hand are removed, the remaining material is roughly that portion passing the #40 screen. See Table 4-3.

Practice with materials of known percentages will be helpful in perfecting these techniques.

Table 4-3 Particle sizes

Term	Particle Size	Examples
Gravel	3" to approx. 1/4"	Lemon to Pea
1. Coarse	3" to 3/4"	Lemon to Walnut
2. Fine	3/4" to #4	Walnut to Pea
Sand		
1. Coarse	#4 to #10	Pea to Rock Salt
2. Medium	#10 to #40	Rock Salt to Table Salt
3. Fine	#40 to #200	Table Salt to Powdered Sugar
Fines	Less than #200	

FIELD TESTS

Determining Whether a Material is Primarily Coarse or Fine Grained

Test 1

Spread the sample on a flat surface and examine the particles to determine the approximate grain size by visual inspection. If more than 50 percent of the sample has individual grains that are visible to the naked eye, the material is coarse. If less than 50 percent, it is a fine material.

Aggregated dry particles may appear to be sand sized grains to the eye. Saturating the sample will break these aggregated particles down. By rubbing the wetted soil between the thumb and forefinger, sand sized grains can be detected as they will feel rough and gritty. Practice with samples with known percentages of sand will be helpful in estimating sand percentages.

Test 2

Fill a straight sided glass bottle to approximately 0.4 of its height with the sample, then nearly fill the bottle with water. Shake until all the material is in suspension. Estimate the percent that settles in 25 seconds. If more than 50 percent of the material settles in 25 seconds, the material is coarse grained. If less than 50 percent of the material settles in 25 seconds, the material is fine grained.

Classifying Coarse Grained Materials

Test 1

Spread a representative sample on a flat surface. Determine whether more than 1/2 of the visible grains, by weight, are pea size or larger. If they are, it is a gravel; if not, it is a sand.

After determining if the material is a gravel or sand, it is further classified according to the properties of the fine content of the material. To do this, remove the coarse material that can readily be manipulated with the fingers. This can be done by spreading a thin layer of material on a surface and rolling the coarse particles to the edge or by placing a thin layer on a sheet of paper and tapping the coarse materials to the edge. Saturate the remaining material and work it in the hands. The hands will not be stained if there are less than 5 percent fines. It will be GW or GP if the material is a gravel or SW or SP if the material is a sand. The hands will be stained when there are more than 12 percent fines. Weak casts can be formed from moist material. It will be GM or GC if the material is a gravel or SM or SC if the material is a sand.

Dual symbol materials (5 to 12 percent fines) cannot be readily classified by field procedures.

Use a second sample if there are less than 5 percent fines. Spread it out and observe the grain size distribution. If the coarse material consists of fairly well distributed particle sizes, the material is a well graded gravel or sand (GW or SW). If the coarse material consists chiefly of one size particles or of large and small particles with in-between sizes missing, the material is a poorly graded gravel or sand (GP or SP).

When there are more than 12 percent fines in a coarse grained material, make the plasticity tests on the fines described below under Classifying Fine Grained Materials to determine whether the material is clayey or silty.

The material will be GC or SC if clayey and GM or SM if silty.

Classifying Fine Grained Materials

Remove coarse material from the sample as explained above.

Test 1

To make the dilatancy test, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water to make the soil soft but not sticky. Place a pat in the open palm of the hand and shake it horizontally. A positive reaction is indicated by the appearance of water on the surface of the pat. The sample will leave a glossy appearance. The water and gloss will disappear from the surface when the pat is squeezed between the thumb and forefinger. The rapidity of the appearance of water during the shaking and of its disappearance during squeezing assist in identifying the character of the fines in the soil. An ML will have a rapid reaction; an MH and CL, a slow reaction; and a CH, no reaction.

Test 2

Dry crushing strength is estimated by crushing a dry clod between the fingers. A block of soil at least 3/4" in smallest dimension should be used as smaller samples may give erroneous results. Easily crushed material of low strength is an ML. Medium strength material is either a CL or MH. CH material is almost impossible to break.

Test 3

The toughness test uses the same procedures that are used in the laboratory to determine the plastic limit (PL). Wet and mold a soil sample so that it can be rolled into a thread without crumbling. The material will not stick to the hands if the correct amount of water is added. Roll the moist soil with the palm of the hand on any clean, smooth surface such as a piece of paper, to form a 1/8 inch-diameter thread. Gradually reduce the moisture content by breaking up the sample and remolding and rolling it until the 1/8-inch thread breaks into pieces approximately 3/4" long. The material is then at its plastic limit. Circumferential breaks in the threads are an indicator of a CH or CL material. Longitudinal cracks and diagonal breaks are an indicator of a MH material.

Remold the sample into a coarse thread and pull it apart. A tough thread indicates high plasticity (CH or CL). A medium tough thread indicates an MH material. A weak thread indicates an ML material.

Test 4

To make a ribbon test, use a sample with a moisture content at or slightly below the plastic limit. The ribbon is formed by squeezing and working the sample between the thumb and forefinger.

A weak ribbon which breaks easily indicates an ML soil. A hard ribbon which breaks fairly readily indicates an MH soi. A flexible ribbon with medium strength indicates a CL soil. A strong, flexible ribbon indicates a CH soil.

Test 5

A test for stickiness can be made by saturating material and letting it dry on the hands. An ML soil will brush off with little effort. A CL or MH soil rubs off with moderate effort when dry. A CH soil requires rewetting to completely remove it from the hands.

Test 6

To make a Liquid Limit (LL) test, take a pat of moist soil with a volume of about one-half cubic inch and add enough water to make the soil soft but not sticky. Rapidly add enough water to cover the outer surface. Break the pat open immediately. A positive reaction has occurred when the water has penetrated through the surface layer. If the water has penetrated, the LL is low. If the water has not penetrated, the LL is high. Visual observation of this phenomenon is much easier in direct sunlight.

Special Condition Test

Odor Test

Fresh damp organic soils have a distinctive, pungent, musty odor.

Acid Test

Hydrochloric acid makes calcium carbonate soils fizz.

Shine Test

In making the shine test, be sure soil is not micaceous. Rub a small clod of air-dry soil with a knife blade. A shiny surface indicates high plasticity. You are seeing the shine of the dry, high plastic fines.

Malachite-Green Test

The staining agent used is a saturated nitrobenzene solution of malachite green. Clay minerals of the kaolinite group merely adsorb the dye, becoming blue to green-blue after application of this solution. Montmorillonite becomes yellow-red and illite becomes purple-red purple.

Acetone Test

Place one part soil and ten parts water (by weight) in a small bottle. Stopper the bottle and shake by hand at 15-minute intervals. Filter the extract through filter paper. Mix a 50-50 solution of the filtrate and acetone. The formation of a milky percipitate indicates the presence of gypsum.

COARSE GRAINED SOILS More than half of the material (by weight) is individual grains visible to the naked eye.	GRAVELLY SOILS More than half of Coarse Fraction is larger than 1/4".	CLEAN GRAVELS Will not leave a stain on a wet palm	Substantial amounts of all grain particle sizes	GW
			Predominantly one size or a range of sizes with some intermediate sizes missing	GP
		DIRTY GRAVELS Will leave a stain on a wet palm	Nonplastic fines	GM
			Plastic fines	GC
	SANDY SOILS More than half of Coarse Fraction is smaller than 1/4".	CLEAN SANDS Will not leave a stain on a wet palm	Wide range in grain size and substantial amounts of all grain particle sizes	SW
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP
		DIRTY SANDS Will leave a stain on a wet palm	Nonplastic fines	SM
			Plastic fines	SC

	RIBBON	LIQUID LIMIT	DRY CRUSHING STRENGTH	DILATANCY REACTION	TOUGHNESS	STICKINESS	
FINE GRAINED SOILS More than half of the material (by weight) is individual grains not visible to the naked eye.	None	< 50	None to Slight	Rapid	Low	None	ML
	Weak	< 50	Medium to High	None to Very Slow	Medium to High	Medium	CL
	Strong	> 50	Slight to Medium	Slow to None	Medium	Low	MH
	Very Strong	> 50	High to Very High	None	High	Very High	CH
HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture.						OL OH Pt

Figure 4-7 Summary of Field Identification Tests

All the tests listed above are field tests meant to aid in the tentative classification of soils. A high degree of proficiency with these techniques can be attained by practicing each test on samples of known classification. They are not precise and are not intended to replace more accurate laboratory methods.

Figure 4-7 summarizes the field tests.

5. PROPERTIES THAT AFFECT ENGINEERING BEHAVIOR OF SOILS

INHERENT SOIL CHARACTERISTICS

Soil Grains

The size, distribution, and shape of soil grains are most important in coarse grained soils. Soil strength generally increases while permeability and compressibility generally decrease with increased size and better distribution.

Plasticity

Plasticity is most important in fine grained soils. Soils with higher plasticity generally have higher cohesion and resistance to piping, erosion, and settlement cracks than soils with lower plasticity.

Density

The density of a soil mass is probably the most important single determinant of the engineering behavior of soils. Soil strength generally increases while permeability and compressibility generally decrease with increased density. Density can be increased by compaction and by consolidation under static loads.

BEHAVIOR CHARACTERISTICS

Strength

Shear strength of soil is made up of two elements, friction and cohesion.

In its simplest form, friction is the resistance to sliding of one block of nonplastic soils against another. It is similar to, and can be assumed to have the same action as, the resistance of a block of wood sliding down a wooden plane. The friction in soil is complicated by such factors as the irregularity of the planes, interlocking of opposite particles, and size and shape of the soil grains. The greater the weight placed on the sliding block the greater force is necessary to cause the block to slide.

Cohesion is the result of the magnetic-like attraction of particles that is noted in one form as the plasticity and stickiness of soils. It resists one block of soil sliding on another, but cohesion resistance does not increase with increased load on the block.

Both friction and cohesion of soils increase with increased density.

Erosion

Resistance to internal erosion or piping follows very closely the soils resistance to surface erosion. Soils with a high susceptibility to sheet erosion also have a high piping potential, and therefore are critical to earth structure safety. In contrast, soils with a low susceptibility to surface erosion such as the more plastic soils do not present an internal erosion problem.

Cracking

Cracking of embankments may be caused by either of two physical actions or a combination of them.

Cracking may be caused by drying. As the soil drys, it shrinks and cracks form. The finest materials develop the highest cracking potential. Plasticity is only an indirect indicator of cracking potential because higher plasticity means finer material. If nonplastic materials have the same grain size as plastic materials their cracking potential is essentially equal.

Cracking due to movement of embankments is a result of both the amount of movement and the deformability of the material. Deformability of embankments is a result of both the plasticity of the material and the water content at which the embankment is built. Generally the lower the water content when compacted the more brittle the embankment and the higher the cracking potential.

Permeability

Permeability depends on both the size and volume of pores in a soil; hence, it increases as grain size increases and decreases as density increases.

Compressibility

Compressibility of a soil deals with how readily and how much it will decrease in volume when subjected to load. Compressibility depends on the volume of voids in the soil, and increases with decreasing density. The amount of settlement that will occur in a soil depends on its compressibility and on the size of the load to be placed on it. Because of grain to grain contacts, coarse grained soils may be nearly incompressible under static loads but may settle from shock or vibration. The finer grained soils are more susceptible to settlement.

Shrink - Swell

High swell potential occurs in highly plastic soil and is related to increase of moisture contents under low loads. The swelling capacity may be estimated from the plasticity index of a soil. Soils with a plasticity index of more than 20 usually have a medium to high swell potential; those with more than 35 normally fall in the very high category. The strength of soils after swelling is greatly reduced.

Upon drying from saturation to the shrinkage limit, soils with a low shrinkage limit will shrink more than those with a high shrinkage limit.

If possible, the placement of soils with a high shrink-swell potential should be restricted to interior zones of embankments where little changes of moisture will occur, and where loads will be imposed which will tend to prevent swell.

Bearing Capacity

The ultimate bearing capacity of a soil is the average load per unit area required to produce failure by rupture of a supporting soil mass. Bearing capacity is important in evaluating the ability of soils to safely support semi-rigid structures through footings, piers, or piles.

6. SITE INVESTIGATION AND USES OF MATERIALS

GENERAL

Field decisions on specific site conditions will develop naturally when adequate information is available.

Good site investigations are dependent upon adequate background information. The first need is to gather and list all the soil and geologic conditions that affect embankment and foundation characteristics for the area being considered. As new information is developed, it should be recorded. The local history and performance of structures in similar areas and under similar conditions should be studied and evaluated.

Higher dams, particularly those over twenty-five feet, need increasingly careful evaluation of foundation and embankment materials. Even dams with less height having known or suspected unusual foundation conditions, low density materials or porous foundation strata should be carefully investigated and a determination made as to the field tests or laboratory tests needed.

A minimum amount of boring and soil classification will suffice for those sites where materials and conditions are similar to other sites in the area where completed structures have performed satisfactorily.

SITE SELECTION

From a soils engineering viewpoint, site selection is foundation selection plus embankment material selection and availability. A good foundation must meet certain requirements which are based on the functions of the structure to be built. The basic requirements are:

1. The foundation, which includes the abutments, must be stable and safe from structural failure.
2. The foundation must not settle or swell enough to damage the structure or reduce its usefulness.
3. Water must not be able to flow through the foundation at a rate that will endanger the stability of the structure or impair its usefulness.
4. The water table desirably should be low enough so as not to make construction excessively expensive.
5. Foundation materials should not be highly susceptible to cracking and internal erosion or piping.

EXTENT OF SITE INVESTIGATION

The base area of the contemplated structure should be carefully examined. Exploration into the foundation should extend as far below a given section as necessary to reveal the conditions important to safe design and construction.

Borrow areas should be explored and samples investigated for each major change in material and for a computed amount of material that is enough to build the structure plus 25 to 50 percent.

EMBANKMENT MATERIAL

Drilling and sampling of the site should be intensive enough to accomplish the following:

1. Classification of materials by the Unified Soil Classification System.
2. Represent a major portion of the available embankment material.
3. Determination of compaction characteristics of the borrow materials by running appropriate tests or using experience data.
4. Evaluation of the in-place moisture conditions of the borrow. Construction may have to be postponed until a drier period if materials are too wet for proper compaction. Moisture will have to be added during construction operations if the soils are too dry.
5. Permit embankments to be designed and placed in accordance with State Standards and Specifications.

6. Suitable embankment material, in sufficient quantity, must be available either on or within an economic haul distance from the site.

FOUNDATION MATERIAL

Investigation of foundation materials may be made with power equipment, augers or hand excavated trenches or test pits. Sampling should be in sufficient detail to:

1. Classify the materials using the Unified Soil Classification System. This may involve wet sieving through the No. 4 and No. 200 sieves for all coarse-grained materials in order to determine the percentages of fine sands and gravels.

2. Represent all changes of material as to depth and area that will affect the stability of proposed structures.

Permeable Layers

Layers will be considered permeable if they are composed of GW, GP, SW and SP. SM's or SC's with less than 15 percent fines and GM's or GC's with less than 20 percent fines will also be considered permeable. Layers will be considered semipermeable if they are composed of CL, CH, ML and MH materials. SM's or SC's with more than 15 percent fines and GC's or GM's with more than 20 percent fines will also be considered semipermeable.

Special control measures for stability are not necessary if the natural semipermeable material overlying the permeable material under a dam equals or exceeds the thickness indicated in the following table:

Table 4-4 Minimum natural blanket thickness

Permeable Layer Thickness	Minimum Natural Blanket Thickness
(Feet)	(Feet)
1	5
2	8
4	11
6	12
8	13
10	14

Where special measures are required they may consist of one of the following:

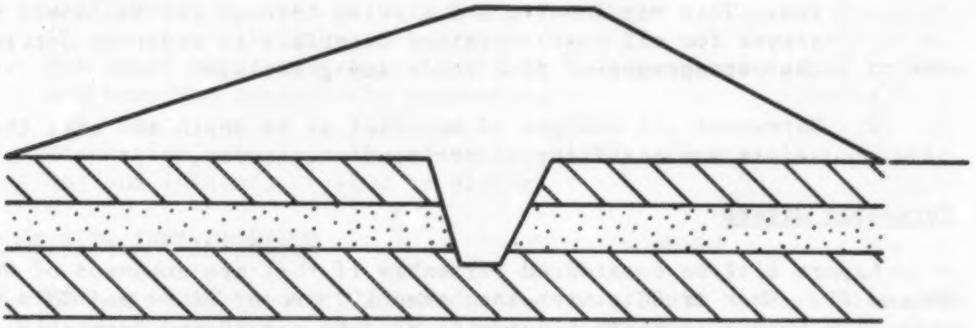
1. Interception of the permeable layer with a cutoff trench.

2. A drain in the downstream portion of the dam penetrating a minimum of three feet into the permeable material. Where

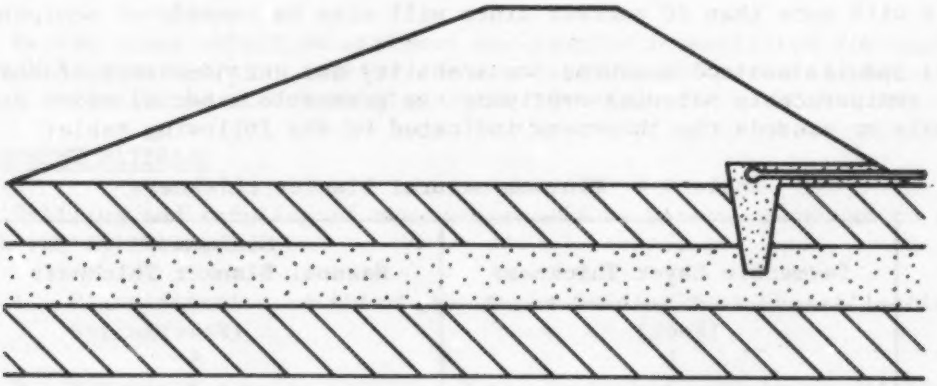
seepage losses from the reservoir are a major factor, the first alternative should be used if at all feasible. See Figure 4-8.

Drains should be positioned at the contact of the foundation and the embankment about 2/3 of the distance from the downstream shoulder to the downstream toe.

Drain material should be a well graded sand or gravel or a designed filter material.



Cutoff



Drain

Figure 4-8 Placement of cutoffs and drains

SPRINGS AND SEEPS

Where springs and seeps occur under the base of the embankment, their point of base flow must be located and uncovered. A drain should then be installed to control the flow of the water until it is clear of the embankment. Water originating upstream of the dam centerline should be conducted upstream and water originating downstream of the centerline should be outletted downstream.

PIPING POTENTIAL

Pipes are formed by underground erosion. Water moving through the soil carries the fine particles away and a series of eroded tubes or tunnels develop. These openings will grow progressively larger and can cause a dam failure. Piping occurs in the same materials that are highly susceptible to erosion on the surface such as fine sands and materials containing nonplastic or dispersed fines. The presence of easily erodible materials in the foundation may call for special treatment. A drain, installed as described under Permeable Layers, is the best protection against piping. The permeable drain material should be designed on the basis of particle size and gradation in relation to the erodible materials. An alternative measure is to completely cut off flow through the erodible material with a trench backfilled with compacted, fine grained, nonerodible material.

DIFFERENTIAL MOVEMENT

When foundation or abutment slopes under the dam embankment are 1:1 or flatter, the embankment normally can be placed without any special measures to protect against differential settlement and the cracking of the embankment that frequently results. Where slopes are steeper, they should be flattened to 1:1 or flatter.

SOLUBLE SALTS

The presence of soluble salts, especially gypsum, in a soil indicates potential settlement problems in the foundation or embankment. High salt content often results in honeycombed or flocculent soil structures. These soil structural units or aggregates may collapse when the soil becomes saturated and loaded.

Where salt content, especially gypsum, is greater than 2 percent in the foundation or 4 percent in the embankment material, technical assistance and laboratory tests should be requested. A soil scientist can help in identifying troublesome gypy or other salty soils.

CONFIGURATION OF SITE

In "V" shaped valleys extra care is needed to be sure that a proper contact between embankment and foundation material is obtained in and near the bottom of the "V". The principal spillway should be located where it can be installed using all standard procedures.

Abutment slopes steeper than 1:1 can pose a problem. Proper contact between the abutment and embankment is difficult to accomplish and will often require special attention, such as flattening the abutment slope. Cracking due to differential settlement is also a danger with steep abutments.

STRATIGRAPHY

Soil layers that have been laid down in valley bottoms by water pose a problem in determining how far they extend. A highly permeable layer that extends under the structure from the pool area and outlets downstream is a threat to the safety of a structure. So is a layer that stops under the downstream toe of the structure because high water pressures can develop. Very soft layers that lie between nominally strong layers can also threaten the safety of the structure.

How deep a rock layer is weathered needs to be determined when the weathering creates one of the conditions already described as dangerous. If the rock face is covered by a layer of soil material, the needed investigations are more difficult.

Water table location is important to design and construction. Water at or near the surface may prevent construction or require counter measures, such as predrainage. At best, it is likely that such a condition will make construction more difficult and costly. Seasonal variations in water table need to be determined.

ENGINEERING FIELD MANUAL

CHAPTER 5. PREPARATION OF ENGINEERING PLANS

Compiled by: W. R. Stanley, Construction Engineer, SCS, Portland, Oregon

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ENGINEERING FIELD MANUAL

CHAPTER 5. PREPARATION OF ENGINEERING PLANS

1. GENERAL

DEFINITION

The preparation of engineering plans is the orderly process of collecting, recording, and analyzing all the facts and data needed to arrive at a satisfactory solution to a problem.

The final engineering plan usually is presented by graphic and narrative methods which outline the kind, scope and quality of work to be accomplished.

INTRODUCTION

The material presented is to be used as a guide in analyzing site conditions and preparing engineering plans.

Of primary importance is the need for technicians to collect sufficient data to permit them to identify the problem and its scope before attempting to develop a plan for getting rid of the problem.

Of equal importance is the need to: 1) Follow a systematic approach in the collection of site information; 2) consider alternate solutions; and 3) use accepted procedures for developing designs and plans for conservation measures as outlined in this manual.

This chapter has application in the development of plans and specifications for conservation practices that are normally developed and installed by the work unit staff, using standard forms, designs, and specifications. However, it also includes elements of the engineering process required for more complex plans.

2. PLANNING PROCEDURES

GENERAL

Certain basic steps should be taken in analyzing the problem and preparing the engineering plan for conservation measures, regardless of the size and complexity of the work. The same process of thought and action applies whether the job involves a simple irrigation turnout structure or a large dam or major group enterprise.

The basic steps are:

1. Identification of the problem and its scope.
2. Site investigation.
3. Collection of basic design data.
4. Assembly and analysis of data.
5. Design.
6. Preparation of plans and specifications.
7. Review and approval of plan.

The work unit technician needs to recognize the importance of an earl appraisal of the size and complexity of the job in terms of classification and approval. Project requests that apparently are in a class beyond the scope of the work unit's approval should be referred immediately to a higher level. Such timely action may prevent the loss of valuable time.

COLLECTING DATA

Identification of the Problem

Owner's Proposal

A clear understanding of the objectives of the proposed measure(s) is essential. The specific requirements should be discussed with the cooperator on the site. Often the cooperator has given considerable thought to the problem and its solution, and his suggestions may be helpful in analyzing the problem and its scope.

Need and Feasibility

In the preliminary review of the proposal, consideration should be given to the existing and potential damages and the feasibility and need for the work. Requests for structures or practices that apparently are not feasible or needed should be fully discussed with the cooperator and other interested parties, leading to withdrawal of the request or acceptance of an alternate measure.

Alternate Methods

After considering the site conditions and objectives to be met, consideration needs to be given to other solutions that appear to have merit. The more desirable alternates should be discussed with the cooperator. Further investigation and planning is then directed to the analysis of those corrective methods.

Site Investigations

Available Data

The site should be studied to define the detail and extent of the needed investigations. All available data, such as soils, geology, hydrology, and climatology of the site should be reviewed and a decision made as to the amount of additional data required to design the conservation practice. Consideration of pertinent data that may be available in reports or papers prepared outside the Service also may be helpful.

Collecting Additional Data

Arrangements for collecting additional data usually need to be started at an early date. Occasionally the cooperator will be asked to help in collecting the data. His assistance should be discussed and a firm schedule agreed upon. Service personnel and equipment also should be scheduled so that action may proceed in an orderly manner.

Collecting Basic Design Data

General

The following items represent data that may be required to develop an engineering plan. All items may not apply for the average situation, but additional investigations will be required for complex projects. The technician should carefully analyze the available data and arrange for the collection of the additional information needed.

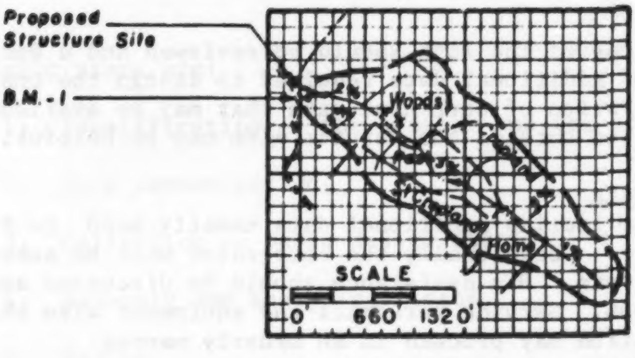
Watershed Map

All watershed information pertinent to the analysis and design of the proposed works should be assembled and recorded on a prepared form or a map. The degree of detail needed will depend upon the complexity of the structure or measure. Watershed information used for the analysis and solution of the problem requires determination of the contributing watershed, characteristics of the watershed, and the location of the proposed works in the watershed. Such information may include some or all of the following: (See Figure 5-1.)

1. Average slopes of various reaches of the principal watercourses.
2. Average slope of the land in various parts of the watershed. (Generally this can be obtained from the soil survey map.)
3. Land use broken down into cropland, grassland and woodland.
4. Area of each of the predominant soil types or groups within the watershed.
5. Location of the proposed work, by symbol.
6. Section or subdivision corners and legal description.
7. Names and extent of property ownership on large watersheds.

A watershed map may be prepared by one or a combination of the following methods:

1. Drawing information on an aerial photograph.


Proposed Structure Site
B.M.-1
Woods
Home
SCALE
0
660
1320'

Traced from aerial photograph

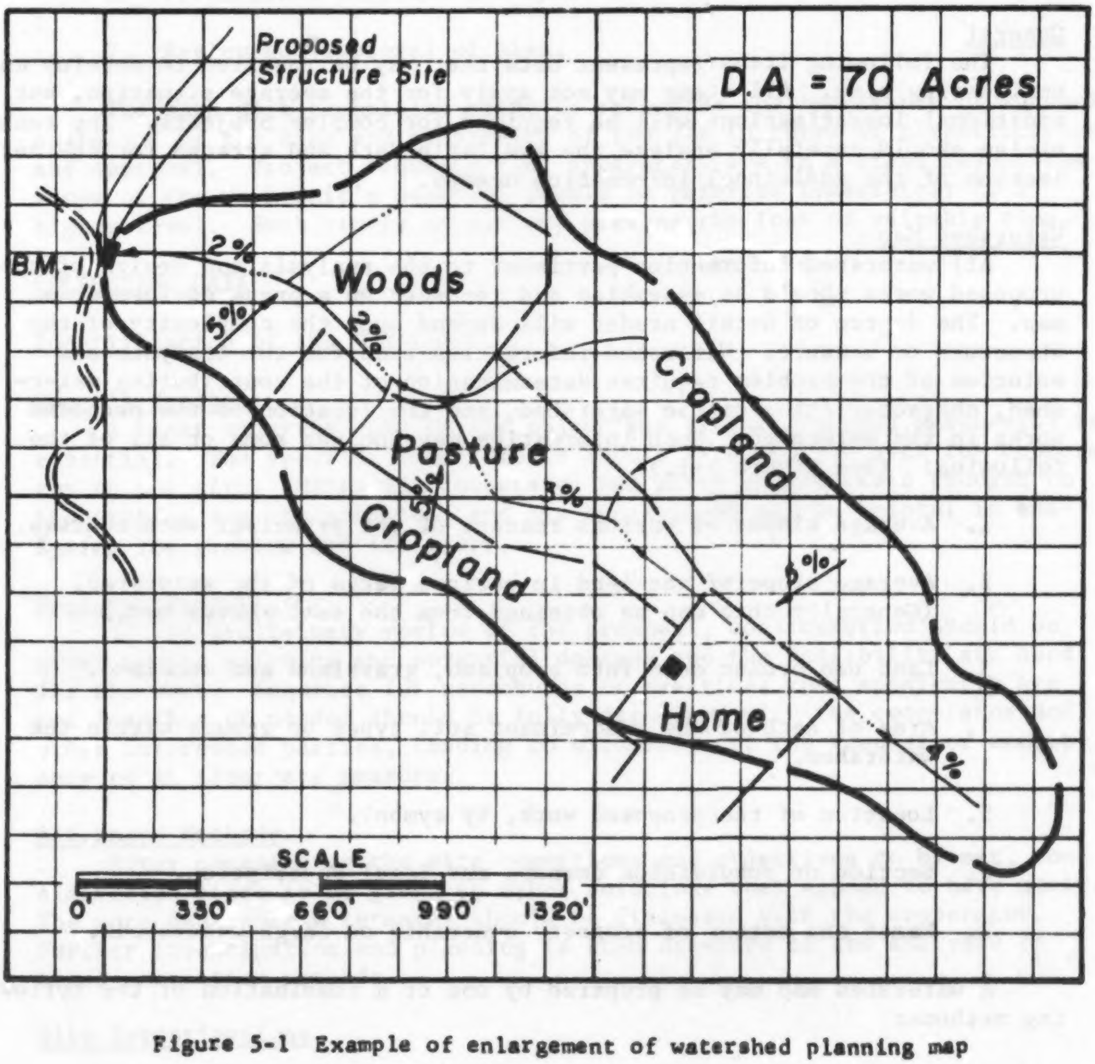

Proposed Structure Site
D.A. = 70 Acres
B.M.-1
2%
Woods
5%
2%
Cropland
Pasture
5%
3%
Cropland
5%
Home
4%
SCALE
0'
330'
660'
990'
1320'

Figure 5-1 Example of enlargement of watershed planning map

2. Tracing from aerial photograph to a work sheet.

3. Enlarging aerial photograph data by proportioning on cross-section paper or enlarging directly with a pantograph.

4. Drawing information on a USGS topographic map.

Location (Topographic) Map

The location drawing is used for detail planning and for staking out the job. It is commonly known as a plan view of the proposed works. Generally, it is drawn to a scale larger than the watershed map, but may be combined with a watershed map on some of the smaller jobs, especially on small drainage work. Discretion should be used in making such a combination, inasmuch as all information needed should be on such a map. It must be clear, understandable and without undue cluttering of the drawing. A location map should show as many of the following items as are needed in the design, construction, and future maintenance of the job.

1. Location of survey centerline, or other survey lines, with ties to permanent objects.

2. Location and plan view of all features (including horizontal dimensions) of proposed works with reference to survey lines.

3. Location and elevation of bench marks.

4. Location of existing watercourses, ditches, tile lines or other features when these affect design.

5. Location of soil borings.

6. Surface or subsurface water elevations at time of investigation.

7. Location of existing fences, property lines, buildings, roads, culverts, bridges, springs, wells, borrow pits, etc.

8. Contour lines.

Profiles and Cross Sections

To prepare engineering plans it is often necessary to have detail data showing the shape and elevation of the existing ground at the site. Normally, profiles and cross sections are used for obtaining and recording such field data. The detail and accuracy of the survey should be in line with the complexity of the site and the structure design.

Soils

The engineering qualities and land capabilities of the soil are important in determining the feasibility of a structure site or practice application. Logs of soil borings or other explorations are used to determine:

1. Adequacy of the foundation materials to support the structure.

2. Ability of a reservoir site to hold water.

3. Suitability of the materials for embankment or channel construction.

4. Drainability of soils for effective drainage systems.

5. Depth to rock, groundwater, or other conditions that may affect the structure.

The depth, method, and scope of the soil and foundation investigations will vary depending upon the size of structure and the hazard of the site. Often adequate investigation can be made with the soils auger. When observation of undisturbed materials is required, the use of heavy equipment such as backhoes and bulldozers has proven to be efficient and economical. All points at which investigations are made should be numbered and plotted on the plan map, and the findings recorded.

The technician should consult with soils and geology personnel if there is any question of suitability of the materials or site.

Hydrologic

Most conservation structures control, store, or provide discharge capacity for a certain volume or flow of water. The expected safety and efficiency of the structure is related to the accurate determination of the design runoff volume or peak discharge of the contributing drainage area or other source of supply.

The capacity of a structure installed to control unregulated streamflow often requires the collecting of existing rainfall and stream discharge records. The determination of design quantities, unless otherwise directed, is made by procedures outlined in Chapter 2 of this manual.

Hydraulic

Certain site data and capacity information are required to evaluate the hydraulic requirements of the structure. Items that often require consideration are:

1. Alignment and slope of stream or constructed channel.

2. Grades and cross sections.

3. Critical elevations.

4. Upstream and downstream capacities and controls.

5. Streambed conditions including bedload and deposition patterns that affect velocity and erodibility.

6. Rate of release from controlled supply.

7. Design flow from hydrologic data.

Assembly of Data

After collecting the necessary field and other pertinent data, it is important that all the facts and information be arranged and recorded in an orderly manner. Survey notes should be reduced and plotted in accordance with standard methods applicable to the job. Time can be saved by plotting field data to the scale and detail in the preliminary phase that will suffice for final design and preparation of plans for the project.

For many projects the use of prepared "work" or "job" sheets can be used to record all of the necessary data. These approved standard forms should be used, insofar as practical, for recording the data needed for analyzing the problem and the planning of a practical installation.

Analysis of Data

In reviewing the collected data, it is important to consider the relationship of the proposed solution to the overall use of the land. How will it affect needed practices to be installed in the future, and will the proposed practice be practical and needed if other measures are applied?

Detail review is necessary to determine:

1. The type or series of measures required.
2. The limitations in location and size of facility imposed by the site.
3. The design procedures and criteria that apply to the proposed structures or practices.

Throughout the process of analysis, consideration needs to be given to alternate methods and construction materials. A small additional outlay in installation cost may prove a saving in future maintenance and operation. All of these considerations should be discussed with the cooperator before preparing the final designs.

DESIGN

Design procedures include:

1. Rechecking or refining the estimated (Q) flow.
2. Hydraulic calculations to provide control, capacity, and safety.
3. Structure design.
4. Location, dimensions and elevations of important parts of the structure and its appurtenances.
5. Estimate of material quantities.

6. Specifications for materials and construction.

7. Estimate of construction costs.

Each phase of design should be performed by prescribed Service methods. It is important that design calculations be documented in a neat, orderly manner and checked for accuracy. Figure 5-2 illustrates a format for laying out a typical design problem, and a systematic procedure for documenting the work.

CONSTRUCTION DOCUMENTS

Drawings

The preparation of the construction plans or drawings consists of recording the design and structural requirements graphically in enough detail so that a technician unfamiliar with the project will have adequate information to lay out and see that the work is constructed as designed. Construction drawings for complex structures usually involve drafting the topographic, cross section and profile data collected in the investigation stage. Additional layout and detail drawings, as required, may be prepared as the design calculations are completed.

For many on-farm measures the preparation of the construction drawings may be simplified by using approved standard predesign layouts. The standard drawings (national and state forms) require careful review to see that: 1) The plan as drawn will fit the site so that the structure will function properly; and 2) all required dimensions, elevations and modifications are complete.

A common error in the preparation of the construction drawings is the omission of required details, sections, and dimensions. All plans should be carefully reviewed for completeness and accuracy before they are approved and delivered to the cooperator.

Specifications

In addition to the detail construction drawings, the construction plan often requires written specifications to clarify how the work will be done, the quality of workmanship, and methods of testing.

Another important phase of the specifications is the listing of the required quality of the manufactured materials that will be used in the work.

For small projects, the material and construction specifications may be documented in the form of notes on the drawings. For larger projects, the preparation of a separate specification document or the use of state standards is more practical. Otherwise the drawings become so cluttered they lose their usefulness.

COMPUTATION SHEET
SCS-522 REV 5-56

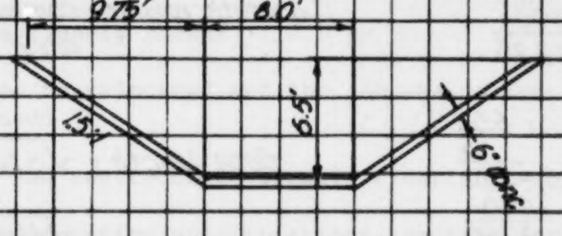
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE 5-9

Example Problem

STATE Your state		PROJECT Red Sands Irrigation Co.		
BY F.K.M.	DATE 1-15-68	CHECKED BY J.L.M	DATE 1-17-68	JOB NO. BCSCD-10-68
SUBJECT Cost estimate, Lining - Kingman Lateral				SHEET 1 OF 2

Data: L = 1230'

6.5
1.5
325
65
9.75



Problem: 1. To determine volume of excavation
2. To determine volume of concrete
3. To prepare a cost estimate

9.75
6.5
4875
5850
63.375

6.5
8.0
5200
63.375
115.4

Excavation - area of trapezoid × length

Area = (8.0 × 6.5) + 2($\frac{6.5}{2}$ × 9.75) = 115.4 sq ft

Volume = (115.4 sq ft × 1230 ft) = 141,942 cu ft

115.4
1230
34620
2308
1154
141,9420

$\frac{141,942}{27}$ = 5,257 cu yds

5257
27)141,942
135
69
54
154
135
192
189
3

Note: Use left margin for scratch calculations

Dimensions used for quantity calculations are not exact in every detail. They represent common practice and suffice for field estimates.

Fig 5-2 Example format for documenting design calculations (Sheet 1 of 2)

COMPUTATION SHEET
SCS-522 REV 5-56

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

5-10 Example Problem

STATE Your state		**PROJECT** Red Sands Irrigation Co.		
BY F.K.M.	**DATE** 1-15-68	**CHECKED BY** J.L.M.	**DATE** 1-17-68	**JOB NO.** BCSCD-10-68
SUBJECT Cost estimate, Lining - Kingman Lateral				**SHEET** 2 **OF** 2

6.5
6.5
325
390
42.25

Concrete volume - compute channel cross-section along Subgrade Surface.

6.50
1.5
3250
650
9.750
9.75
4875
6825
8775
95.0625

slope length = $\sqrt{6.50^2 + (1.5)(6.50)^2}$

$\sqrt{42.25 + 95.06} = \sqrt{137.31}$

= 11.7'

x sectional length of lining.

(2) (11.7) + 8.0 = 31.4 ft

42.25
95.06
137.31

concrete volume

11.74
$\sqrt{137.3100}$
1 | 1
21 | 37
21
227 | 1631
1589
2344 | 4200
4376

(31.4) (0.5) (1230) = 19,311 cu ft

$\frac{19,311}{27}$ = 715 cu yds

15.7
1230
4710
314
157
19311.0

715.2
27 | 19311.0
189
41
27
141
135
60

Cost Estimate

excavation - 5257 cu yds @ $ 0.65/cu yd = $3417.05
concrete - 715 cu yds @ $80.00/cu yd = 57,200.00
$60,617.05
say $60,620

5257
.65
26285
31542
3417.05
715
80
57,200.00

Note: Normally these computations would be made on the slide rule. This problem was made to demonstrate problem analysis and setting the problem down on standard service computation sheets.

Fig. 5-2 Example format for documenting design calculations (shts 2 of 2)

Check List

The amount of detail required in the construction plans will vary with the type and size of the job. All jobs, regardless of size, should be adequately planned. The following list may be useful in checking the adequacy of the drawings and specifications:

1. Can the farm be located from the plans?
2. Is the project site clearly shown?
3. Can the survey lines be relocated and the job staked for construction as designed?
4. Are all dimensions and construction details clearly shown?
5. Are material and construction specifications complete for all parts of the work?
6. Are material quantities shown?
7. Has the title block been completely filled, including the date and who designed, drafted, and approved the work?
8. Has the cost estimate been prepared?

FINAL REVIEW AND APPROVAL

Before the construction plans are delivered to the cooperator a review of the design and construction plans should be made by a technician other than the one preparing the design.

When required, plans should be submitted to the appropriate state technical level for approval. The construction plans also should be properly signed and dated by all parties involved in their preparation and approval.

RECORDS

A complete copy of survey notes, useful basic data, soils logs, design calculations and other pertinent data, including a copy of the plans and specifications, should be assembled and filed in an orderly manner at the field location.

All structures or practices, regardless of type or kind of material, will require maintenance. Changes or additions made during construction should be recorded in colored pencil on the office copy of the plans. These "as built" plans often are useful when making maintenance recommendations to the cooperator. They also are useful to the Service for structural design improvement and evaluation of hydraulic performance. Complete "as built" records may be valuable in case of a legal dispute.

3. DRAWINGS AND DRAFTING STANDARDS

PREPARATION OF DRAWINGS

General

Drawings prepared in outline form, and standard job sheets are available in most states for many of the commonly used conservation structures and practices. These forms provide space for recording planning, layout, and construction details. Their use is applicable to the less complex jobs that require only the data suggested on the form to do an adequate job of planning and construction.

The technician should be aware of such State forms and state-selected national forms and use them insofar as they have application to the solution of the problem.

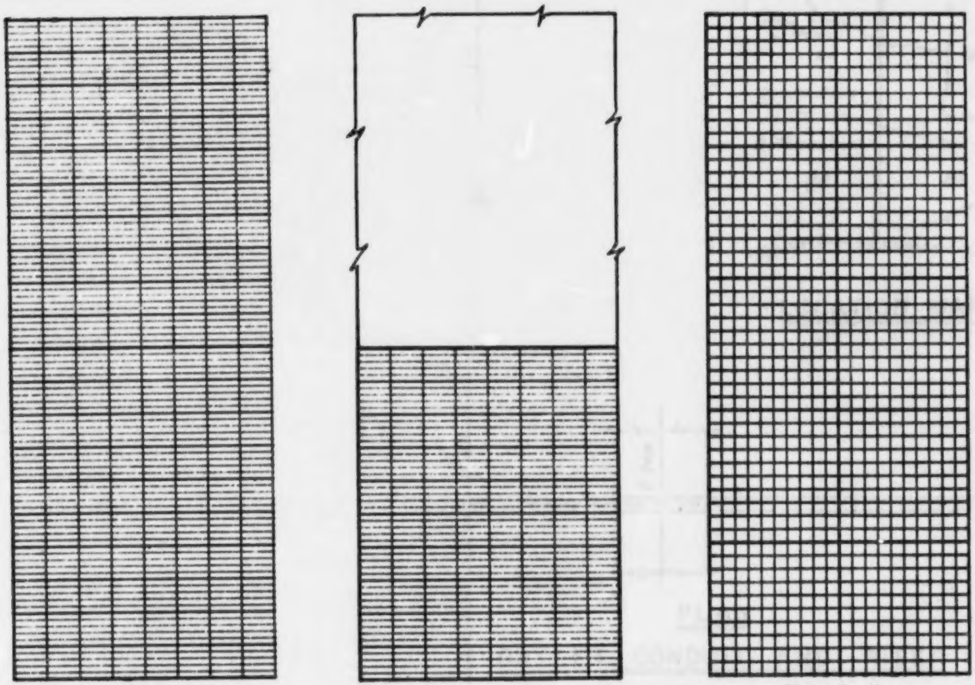
Kinds of Paper

Numerous kinds and types of engineering drafting paper are available through Service supply channels for use in preparing engineering plans. Due to the variance in kinds of practices encountered at the field level, it is not practical to present a list of drafting paper that may be required for all situations. The following kinds have universal use and are commonly stocked in field offices.

1. Profile - tracing or opaque, ruled 4 x 20 to the inch. Figure 5-3.
2. Plan Profile - tracing or opaque; upper one-half of the sheet blank and the lower one-half ruled 4 x 20 to the inch. Figure 5-3.
3. Cross Section - tracing or opaque; ruled 10 x 10 to the inch. Figure 5-3.
4. Plain White - tracing or opaque.

The profile and cross-section types of paper are recommended for use when plotting all kinds of profile or cross-section data, though the project may be small. The habit of documenting data in a systematic, acceptable manner speeds up plan preparation and helps to eliminate errors, both in design and construction.

The plan profile paper has dual use. The upper plain section is used to plot location, alignment, topographic features, etc. The lower half is used to plot ground and design profiles, which reflect the vertical control such as elevations, slopes, grade changes, size of pipe, etc. See example, Figure 5-4. The profile stationing should be directly related to the plan view presented on each sheet. For many small jobs this type of paper will be adequate to plan and construct the complete job.



Profile Plan Profile Cross Section

Figure 5-3. Sample paper - engineer rulings

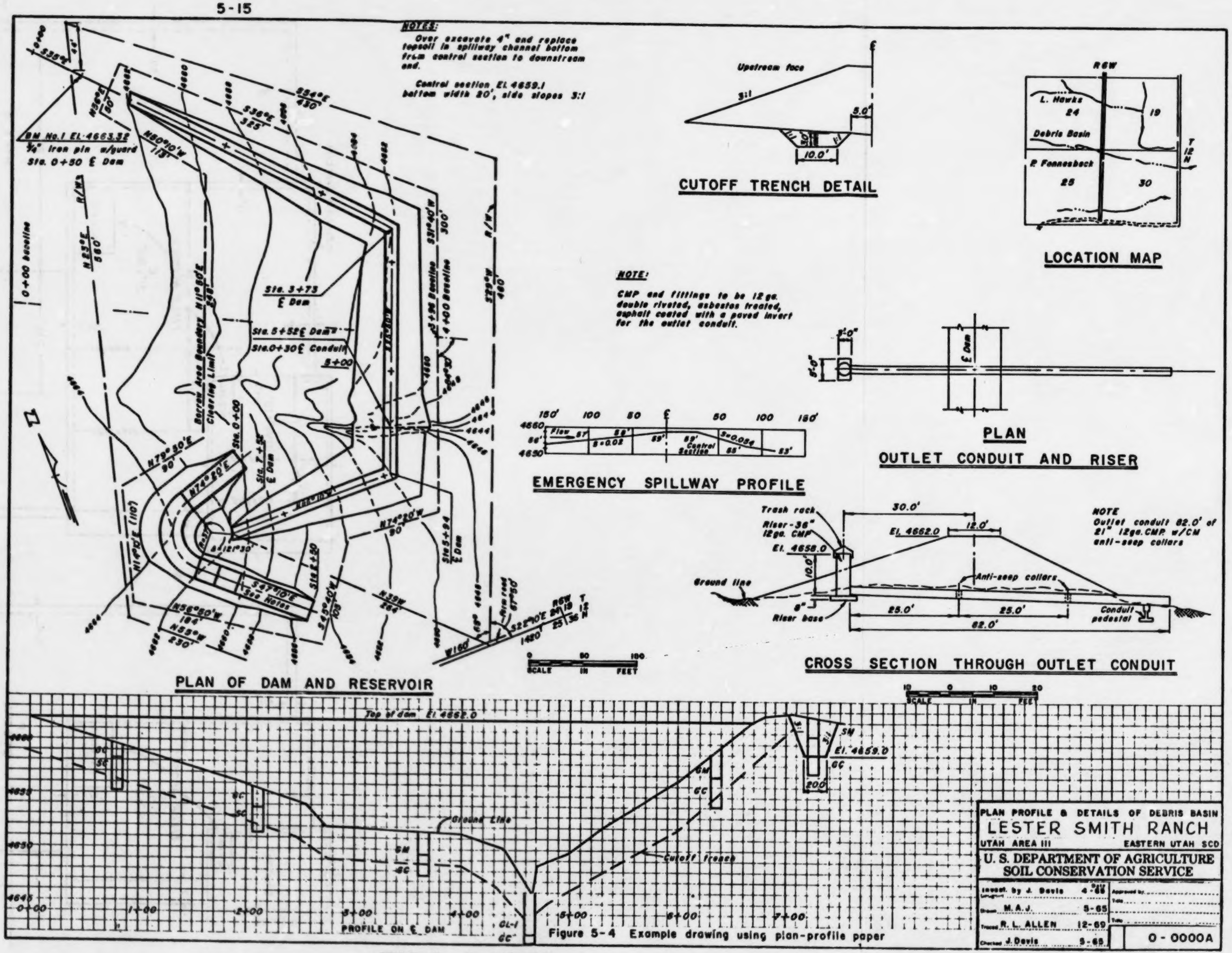
Typical cross sections and structure details may be adequately arranged on the sheet to complete the plan.

Plain sheets are used for preparing watershed maps, location (topographic) maps and detail layout drawings.

Size of Drawing Sheets

All drawings for a job, regardless of kind of paper used, should be prepared on the same size sheet. This practice has advantage for use in the field, as well as appearance and ease of filing. The standard size sheets used by the Service should be used for all engineering drawings. The overall size and layout details, as suggested by the Cartographic Division, are shown in Figure 5-5.

The selection of the most practical size for a job is dictated by the size of the project. In no instance should the size or number of sheets be restricted to a degree that necessary sections and detail cannot be clearly shown to scale.


BM No.1 El. 4663.32
¾" iron pin w/guard
Sta. 0+30 ℄ Dam
0+00 baseline
N23°E 560'
S35°E
N56°E 150'
N80°10'W 113'
S36°E 325'
S84°E 430'
S31°40'W 300'
S29°W 480'
Sta. 3+73 ℄ Dam
Sta. 5+52 ℄ Dam
Sta. 0+30 ℄ Conduit
5+00
3+36 Baseline
4+00 Baseline
Borrow Area Boundary N11°30'E 238'
Clearing Limit
Sta. 0+00
Sta. 7+32 ℄ Dam
N79°30'E 90'
N74°20'E
N74°20'W 90'
Sta 5+94 ℄ Dam
Δ=121°30'
N11°30'E (110')
S47°10'E
See Notes
N56°20'W 194'
N53°W 230'
S40°40'W 105'
N39W 244'
W150'
S22°10'E
1420'
R6W T 12 N
24 19
25 30
R/W
4660 4650 4644 4646 4648 4652 4654 4656 4658
PLAN OF DAM AND RESERVOIR
0 50 100
SCALE IN FEET
Upstream face
3:1
5.0'
10.0'
℄
CUTOFF TRENCH DETAIL
R6W
L. Hawks
24
19
Debris Basin
P. Fonnesbeck
25
30
T 12 N
LOCATION MAP
150' 100 50 ℄ 50 100 150'
4660
4655
4650
Flow
S=0.02
S=0.024
Control Section
EMERGENCY SPILLWAY PROFILE
3'-0"
5'-0"
℄ Dam
PLAN
OUTLET CONDUIT AND RISER
Trash rack
Riser-36" 12ga. CMP
El. 4658.0
10.0'
30.0'
El. 4662.0
12.0'
Anti-seep collars
Ground line
8"
Riser base
25.0'
25.0'
62.0'
Conduit pedestal
CROSS SECTION THROUGH OUTLET CONDUIT
10 0 10 20
SCALE IN FEET
Top of dam El. 4662.0
4660
4655
4650
4645
GC
SC
SM
Ground Line
Cutoff Trench
3:1
El. 4659.0
20.0
GL-I
GC
0+00 1+00 2+00 3+00 4+00 5+00 6+00 7+00
PROFILE ON ℄ DAM

NOTES:

Over excavate 4" and replace topsoil in spillway channel bottom from control section to downstream end.

Control section El. 4659.1 bottom width 20', side slopes 3:1

NOTE:

CMP and fittings to be 12 ga. double riveted, asbestos treated, asphalt coated with a paved invert for the outlet conduit.

NOTE

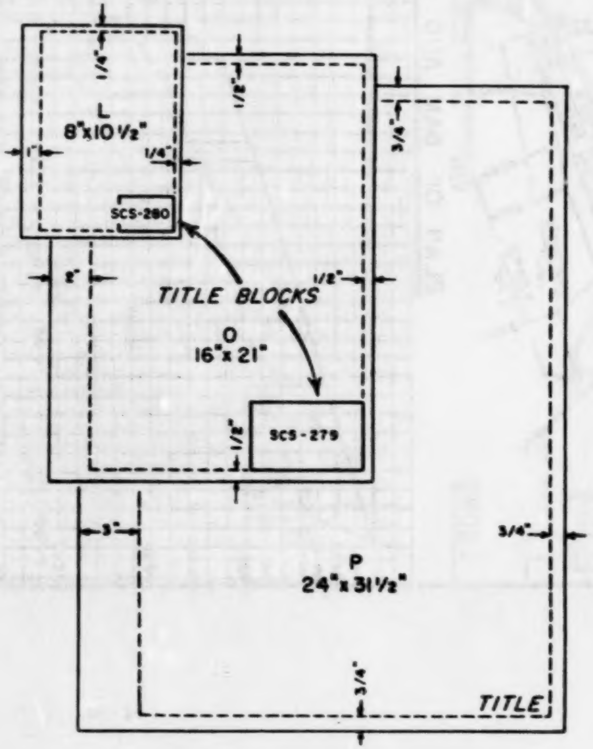
Outlet conduit 62.0' of 21" 12ga. CMP. w/CM anti-seep collars

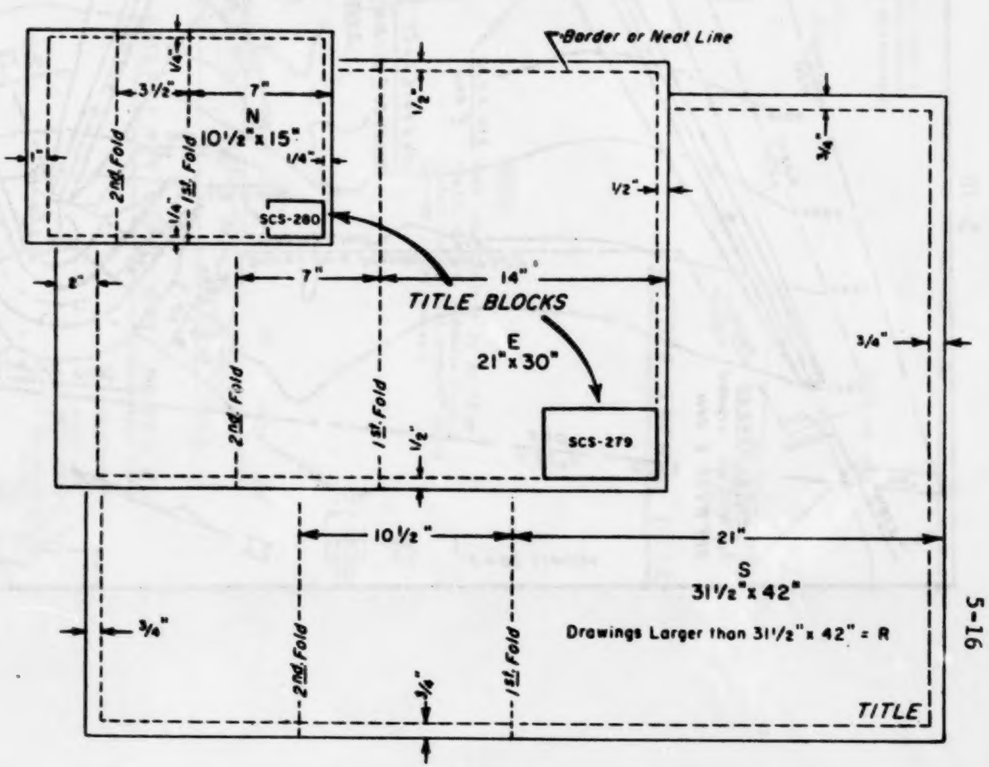
PLAN PROFILE & DETAILS OF DEBRIS BASIN
LESTER SMITH RANCH
UTAH AREA III EASTERN UTAH SCD

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Invest. by J. Davis	Date 4-65	Approved by
Drawn M. A. J.	5-65	Title
Traced R. L. ALLEN	12-69	Title
Checked J. Davis	5-65	0 - 0000A

Figure 5-4 Example drawing using plan-profile paper


L
8" x 10 1/2"
1/4"
1"
1/4"
SCS-280
1/2"
2"
TITLE BLOCKS
1/2"
O
16" x 21"
1/2"
SCS-279
3/4"
3"
3/4"
P
24" x 31 1/2"
3/4"
TITLE


Border or Neat Line
3 1/2"
7"
N
10 1/2" x 15"
1/4"
1"
2nd Fold
1st Fold
1/4"
1/4"
SCS-280
1/2"
1/2"
3/4"
2"
7"
14"
TITLE BLOCKS
E
21" x 30"
3/4"
2nd Fold
1st Fold
1/2"
SCS-279
10 1/2"
21"
S
31 1/2" x 42"
3/4"
Drawings Larger than 31 1/2" x 42" = R
2nd Fold
3/4"
1st Fold
TITLE

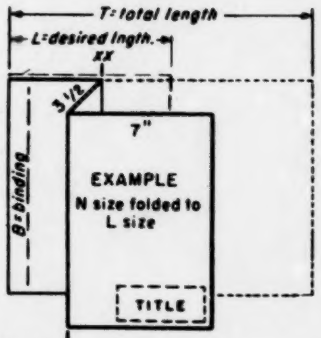
Title and File No. should be consistently graduated through all drawing sizes.

ACCORDION FOLD FORMULA

$L - B = X$ (First Fold) —— $8" - 1" = 7"$

$\frac{T-B-X}{2} = XX$ (Sec. Fold) —— $\frac{15" - 1" - 7"}{2} = 3\,1/2"$

Using this method, title is visible when sheet is bound.


T: total length
L: desired lngth.
XX
3 1/2
7"
B = binding
EXAMPLE
N size folded to L size
TITLE

NOTE: Sheets L, N, O and E are the only sheets authorized for engineering drawings.

Title Blocks should be used only on Engineering and Mechanical Drawings. Engineering Drawings require borders.

TITLE BLOCKS

DRAWING SIZE	DIMENSIONS
"L" and "N"	$1\frac{3}{4}" \times 2\frac{3}{4}"$
"O" and "E"	$3\frac{1}{2}" \times 5\frac{1}{2}"$

Figure 5-5 Standard drawing sizes

When conditions warrant, the layout may be drafted on a larger scale sheet for ease of drafting and then reduced in size by cartographic methods. This is the reason for the related dimensions specified for the standard sheet sizes.

Title Blocks

All sheets prepared for design and construction must have a title block. See Figure 5-6 for Service standard format. A smaller standard title block also is available. Each sheet should bear an individual number and a reference to the total number of sheets prepared for the work; i.e., sheet 2 of 4, 3 of 4, etc.

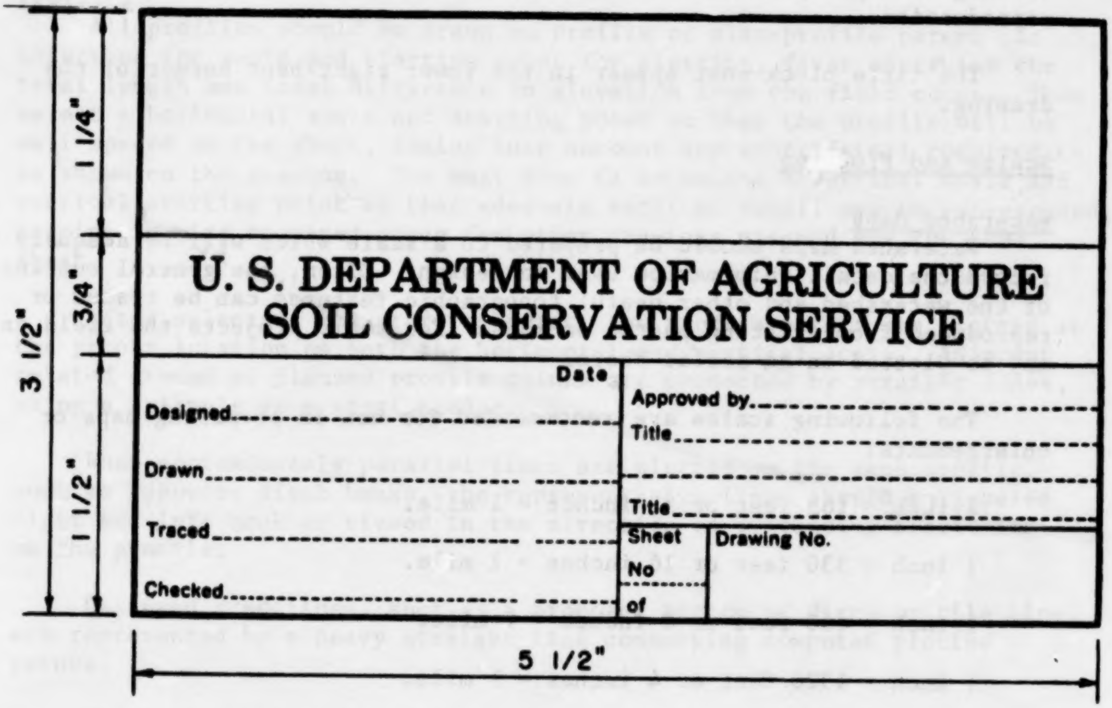

3 1/2"
1 1/4"
3/4"
1 1/2"
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Date
Designed
Drawn
Traced
Checked
Approved by
Title
Title
Sheet
No
of
Drawing No.
5 1/2"

Figure 5-6. Large standard title block

The title block should present the following information in condensed form:

1. Subject matter represented by the drawing (plan, cross section, detail section, etc.). Use job stationing when applicable.

2. Name of project and cooperator or group.

3. Name federal department and Service responsible for preparing the drawings.

4. Name soil conservation district, county and state.
5. Name of persons who designed, drafted and checked the drawings with dates work completed.
6. Signatures of persons submitting and approving drawings, with dates.
7. A drawing number if applicable.

The kinds of drawing paper referred to herein may or may not have the title block printed on the sheets. Prepared title blocks in the appropriate sizes can be obtained as a press stickup which can be attached to the drawing. They may be used without any appreciable loss of clarity in reproduction.

The title block must appear in the lower right-hand corner of the drawing.

Scales and Plotting

Watershed Maps

Watershed maps should be prepared to a scale which will be adequate to record the detail information used in design. Often, the general outline of the watershed and other useful topographic features can be traced or reproduced from existing photos or maps. For small projects the field data may be plotted on an aerial photo.

The following scales are recommended for use in preparing maps or enlargements:

1 inch = 165 feet or 32 inches = 1 mile.

1 inch = 330 feet or 16 inches = 1 mile.

1 inch = 660 feet or 8 inches = 1 mile.

1 inch = 1320 feet or 4 inches = 1 mile.

Location (Topographic) Map

The size of the location map is related to the amount of data required to show the detail characteristics and related locations of the various phases of the work. When contours and other topographical features are complex a large size drawing will be required, as well as a scale using a smaller number of feet per inch. The technician should plan adequate space to prepare a clear presentation of the related topographical features and the necessary structure layout details. A portion of a structure that requires extra sections to show construction limits or detail layout or assembly may be drawn to an even larger scale.

The following scales may be taken as a guide:

Topographic Detail--Use an engineering scale for 1 inch = 20, 40, 50, 100 or 200 feet with contour lines shown 1-, 2- or 5-foot vertical intervals.

Structure Layout and Sectional Detail--Use an architect scale for 1 inch or fraction thereof = 1 foot for all structure or assembly dimensions. For example, 1/4 inch = 1 foot; 1/2 inch = 1 foot, 3/4 inch = 1 foot.

It is common practice to show all structure detail dimensions in feet and inches. The architect scale is subdivided to show feet and inches, which simplifies preparing the drawings to true scale.

Profiles

All profiles should be drawn on profile or plan-profile paper. In selecting the scale and starting point for plotting, first determine the total length and total difference in elevation from the field notes. Then select a horizontal scale and starting point so that the profile will be well spaced on the sheet, taking into account any other detail required to be shown on the drawing. The next step is to select a vertical scale and vertical starting point so that adequate vertical detail may be represented, keeping in mind required space for other drawings planned for the same sheet.

After selecting the starting point, the profile points are plotted at the proper location on both the horizontal and vertical scale. Adjacent related ground or planned profile points are connected by straight lines, using a triangle as a straightedge.

When approximately parallel lines are plotted on the same profile, such as opposite ditch banks, the representative lines should be labeled right and left bank as viewed in the direction of increasing stationing on the profile.

Designed gradelines, such as a proposed bottom of ditch or tile line, are represented by a heavy straight line connecting computed plotted points.

The horizontal scales for profiles should be 1 inch = 20, 40, 80, 100, 200 or 400 feet. Only the heaviest (10th vertical) lines are marked in stations. Using the above suggested scales, these heaviest lines would be 50, 100, 200, 250, 500 or 1,000 feet apart.

The vertical scale should be 1 inch = 2, 4 or 8 feet. Only the heavy (10th horizontal) lines are labeled. Using the above suggested scales the heavy lines would be 5, 10 or 20 feet apart. Every heavy line should be marked to show the complete elevation representing the datum used in the field survey.

Cross Sections

Cross sections should be plotted on cross-section paper (10 x 10 to the inch). They should be plotted as viewed when looking in the direction of increasing stationing of the survey; i.e., from Station 0+00 toward the next advancing station.

The complete profile station at which each cross section was taken should appear under the plotted section. At least two elevations should be shown along the left margin of the section to relate the survey elevations to the cross section as plotted.

The survey centerline, or reference lines used in the field for control, also may be shown on the cross section. For large sections it is helpful to establish horizontal stations for the section, usually stationed 0+00 at centerline and increasing both to the right and left of centerline.

When practical, the cross section should be plotted to the same horizontal and vertical scale, 1 inch = 5 feet, or 1 inch = 10 feet, thereby presenting an undistorted view. When this is not possible, these scales should be altered so that the full section can be shown on the sheet. In such cases, for example, the vertical scale may remain 1 inch = 5 feet or 10 feet, and the horizontal scale increased to 1 inch = 20 or 50 feet. All cross-section sheets should show the horizontal and vertical scale used for plotting.

Soil Logs

The soil borings or test pit data recorded in the field should be included on the construction drawings. All test sites should be accurately plotted to show location and elevation. Standard SCS legend symbols used for recording and plotting log information are shown in Figure 1-19, Chapter 1, of this manual. The boring logs should be plotted on the profiles or cross sections at the locations taken. When adequate room is not available, the location may be shown on the profile and the actual log presented to the side. When test sites do not appear on the profile, the location may be identified on the location map and the log data, properly identified, may be plotted on a separate sheet or at other convenient locations on the drawing.

A word description of the sample material, placed alongside the plotted boring, is helpful and saves time in referring to field data notebooks. Applicable ground water levels with date of observation should be shown on the logs.

The Unified Soil Classification System should be used to describe and log all applicable soil materials.

DRAFTING REQUIREMENTS

General

Engineering work sheets and other drawings prepared by work unit personnel are not expected to be of a drafting quality produced by a skilled draftsman. However, field personnel whose duties require the preparation of engineering drawings are expected to perform such work in a legible, neat, orderly and understandable manner. The appearance of the drawings will affect the degree of confidence with which they are accepted by cooperators and others in and outside the Service.

Equipment and Materials

Due to the various conditions found in work units, it is not possible to prepare a complete list of all materials needed in every work unit for preparing engineering plans. The following includes the drafting supplies generally required in preparing the normal kinds of engineering plans:

1. Paper - the types and kinds of paper listed are available in rolls or standard SCS size sheets with printed border lines and title blocks.

   Profile - tracing or opaque ("N" size SCS-316A; "E" size SCS-316)

   Plan profile - tracing or opaque ("N" size SCS-317A; "E" size SCS-317)

   Cross section - tracing or opaque ("N" size SCS-315A; "E" size SCS-315)

   Plain - tracing or opaque ("N" size SCS-313A; "E" size SCS-313 or 313C)

   Computation pads - SCS-522A or SCS-523 Rev.

2. Applicable standard state and national work sheets and predesign structure sheets.

3. Triangles - 45° and 30x60°.

4. Scales - 12-inch engineer's and 12-inch architect's.

5. Protractor - 360°.

6. Drafting board 3 feet x 4 feet (minimum) with T square.

7. Planimeter.

8. Minor items - F, HB, H, 2H, 3H, and 4H pencils, pencil sharpener, sandpaper pads, scissors, tape, thumb tacks, India ink, pens, lettering guide, etc.

Use of Pencil

Nearly all drawings made at the field level will be done in pencil. With reasonable care, a very creditable drawing can be prepared. If the proper weight lines are used, good photostatic or direct print reproductions can be made. The use of pencil eliminates a great deal of work normally required in making ink tracings. In some cases, however, it may be necessary to do considerable trial layout work in pencil on a contour sketch, as for a contour orchard or terrace system. In such cases it will be desirable to ink in the contours before beginning the trial layout work to avoid erasing the original contour lines.

Lettering

All lettering and numbers within the body of engineering sheets should be 3/20" high for capitals and 1/10" high for lower case letters. On the profile paper this is equivalent to three of the finest lines high for capital letters and two lines high for lower case letters. Titles in title block should be all capitals 1/4" high (five of the finest lines on the profile paper). Avoid the use of lettering any smaller than specified above if the drawings are to be reduced in size; otherwise, the lettering will be difficult to read.

The style of lettering used should be consistent with standard engineering practice. Elementary survey textbooks and the Service Cartographic Units provide examples of acceptable methods of forming letters and numbers. Each technician should practice to become proficient in making uniform lettering.

Standard Symbols

Symbols used in the preparation of maps and engineering plans should be consistent with the national cartographic mapping symbols. Figure 1-18, Chapter 1 of this manual, exhibits some of the more common symbols used in conservation planning.

For more detailed coverage, the technician is referred to the Standard Map Symbols for Soil Conservation Service.

Scales

The scale for all drawings and detail sections should be shown. Sketches or typical sections not drawn to scale should be so noted. For drawings which will not be reduced in reproduction, the numerical scale may be used; i.e., 1" = 100'. However, if the drawings are to be reduced, the numerical scale becomes useless unless the reduction ratio is known. In such cases a bar scale is required.

Reduction of the drawing does not affect the usefulness of this scale since it is reduced by the same ratio as the drawing. Figure 5-1 illustrates this type of scale.

The bar scale should be accurately drawn to the scale used for the view represented, and should include labeled subdivisions so that the use of the scale is simplified.

North Arrows

North arrows should be shown on each watershed map, location plan, and contour map. Technicians may use their own style north arrow so long as it is not too elaborate.

Prepared stick-on standard type north identifications are available from the Cartographic Units. Field locations preparing large numbers of engineering plans may justify maintaining a supply of this type drafting aid.

Legal Descriptions

The location of all proposed structures should be identified by some acceptable manner.

For structures requiring state or other agency approval it is necessary, in most instances, that the structure site be located by actual survey and referenced to accepted legal section or subdivision corners. The legal description should be checked to determine that the correct section, range and township numbers have been recorded.

It is desirable that other improvement sites are located within the proper section and subdivision as accurately as possible from existing map or field data. The legal land description and properly oriented structure site may be shown on the watershed or location map. For minor structures the legal site description may be included in the engineering plan title block.

General location information can be obtained from the Soil Conservation District Map, USGS quadrangle sheets, U. S. Forest Service maps and other acceptable maps.

Bench Marks and Transit Points

It is good engineering practice to establish well identified bench marks and transit points at the time of making the design survey. During the process of making the survey adequate location data should be obtained so that the necessary vertical and horizontal control may be plotted on the construction plans. This is an important detail since someone not familiar with the site may be required to do the construction layout.

In addition to showing the location of the bench marks, the correct elevation and description should be included.

Transit points set in roadways or other locations that may be disturbed prior to construction should be referenced by adequate ties. The description of the ties and location with distances to the transit point should be shown in the field notes and on the construction drawing.

as it may not be necessary.

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Legal Description

The location of all proposed structural [illegible] should be [illegible] [illegible] accurately [illegible].

The engineering investigation will not make property appraisal [illegible] [illegible] investigation [illegible] that the structure site [illegible] [illegible] [illegible] [illegible] and [illegible] [illegible] to [illegible] legal [illegible] [illegible] [illegible] the legal description should be checked to determine that the right-of-way ranges and possible numbers have been recorded.

It is desirable that those investigations [illegible] be concerned with the proper section and subdivision [illegible] [illegible] [illegible] [illegible] [illegible] or field data. [illegible] legal [illegible] [illegible] [illegible] [illegible] [illegible] may be shown on the [illegible] in location [illegible]. [illegible] the legal site description may be included on the [illegible] title block.

[illegible] information can be obtained from the [illegible] Conservation [illegible] office, county [illegible] office, or [illegible].

Bench Marks and Traverse Points

It is good engineering practice to establish [illegible] [illegible] bench marks and traverse points at the time of making the design survey. During the process of making the survey adequate location data should be obtained so that the necessary vertical and horizontal control may be [illegible] at the construction stage. [illegible] [illegible] important installations [illegible] [illegible] [illegible] the site may be required to [illegible] the construction [illegible].

In addition to showing the location of the bench marks, the correct elevation and description should be included.

Traverse points are in reference to [illegible] locations that may be [illegible] [illegible] [illegible] should be [illegible] [illegible] adequate [illegible]. The description of the [illegible] and location [illegible] to the [illegible] point should be shown in the field notes and on the construction drawings.

ENGINEERING FIELD MANUAL

CHAPTER 6. STRUCTURES

Compiled by: Keith H. Beauchamp, Agricultural Engineer, SCS, Lincoln, Neb.

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ENGINEERING FIELD MANUAL

CHAPTER 6. STRUCTURES

1. GENERAL

DEFINITION

A structure is a designed device, constructed or manufactured, used in a soil and water conservation or management system to retain, regulate, or control the flow of water.

INTRODUCTION

Good vegetative practices, together with proper land use, are necessary in a sound soil and water management program. However, vegetative measures and simple practices alone may be inadequate to handle concentrations of water, and do not provide water storage for beneficial use. In such cases, structures are needed.

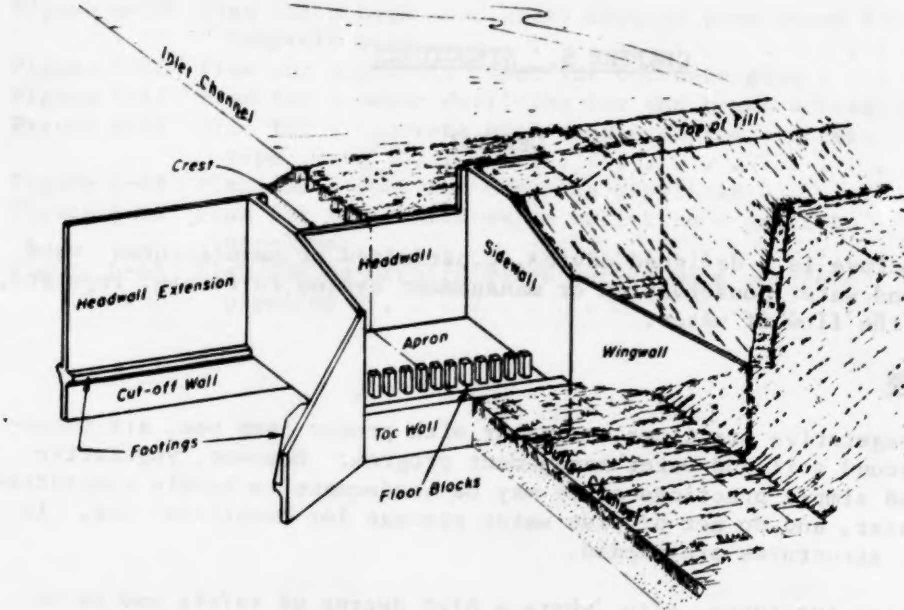
There are instances, also, where a high degree of safety and permanence is desired. Conservation measures may be required to provide insurance against lost of life or destruction of property. Vegetative control measures are subject to the influences of such uncertain factors as climate, diseases and insects, and are not always dependable. On the other hand, properly designed, installed and maintained structures are of long life and dependability.

Structures are used for the following soil and water conservation purposes:

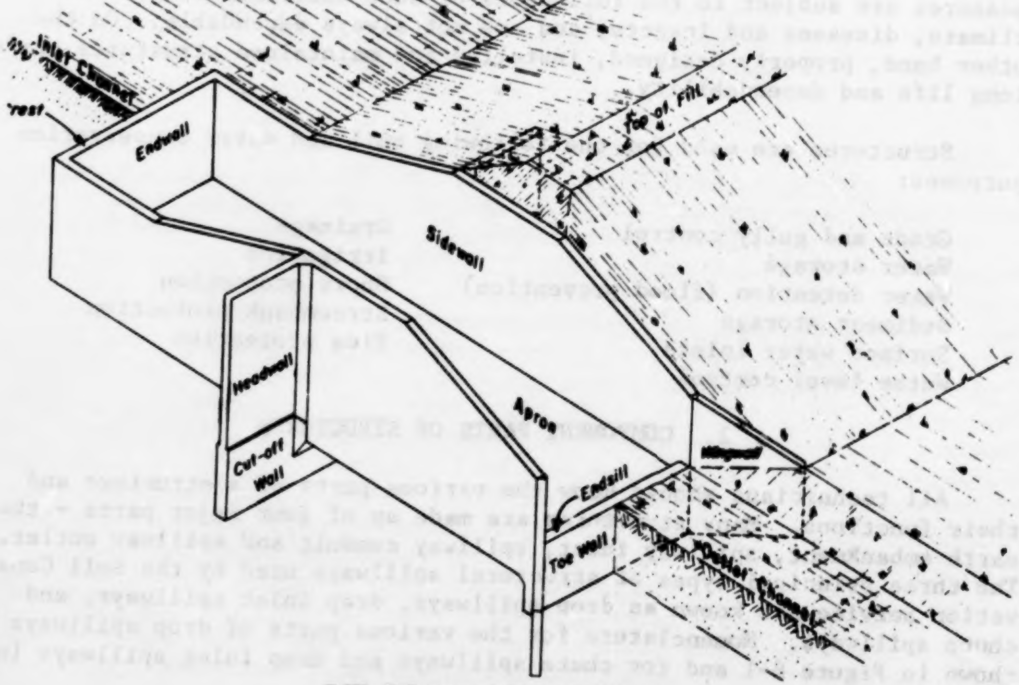
- Grade and gully control
- Water storage
- Water detention (flood prevention)
- Sediment storage
- Surface water inlets
- Water level control
- Drainage
- Irrigation
- Shore protection
- Streambank protection
- Tide protection

2. COMPONENT PARTS OF STRUCTURES

All technicians should know the various parts of a structure and their functions. Many structures are made up of four major parts - the earth embankment, spillway inlet, spillway conduit and spillway outlet. The three principal types of structural spillways used by the Soil Conservation Service are known as drop spillways, drop inlet spillways, and chute spillways. Nomenclature for the various parts of drop spillways are shown in Figure 6-1 and for chute spillways and drop inlet spillways in Figure 6-2.

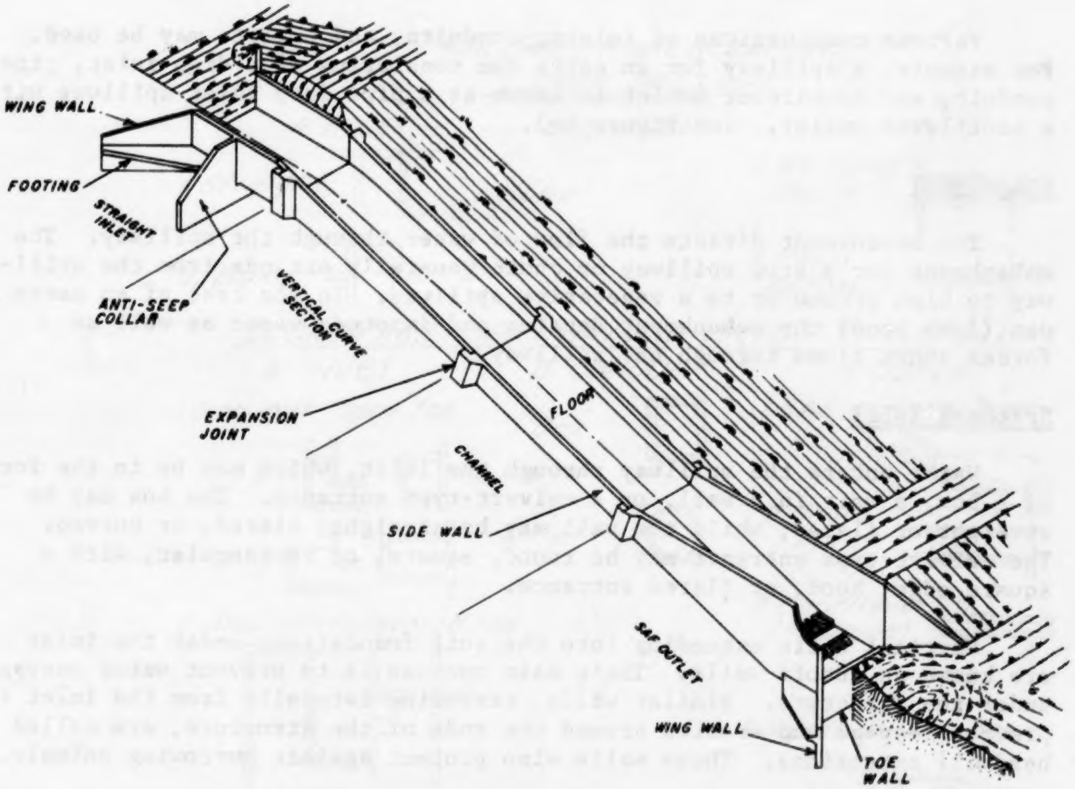

Inlet Channel
Crest
Top of Fill
Headwall Extension
Headwall
Sidewall
Apron
Wingwall
Cut-off Wall
Footings
Toe Wall
Floor Blocks

STRAIGHT DROP SPILLWAY

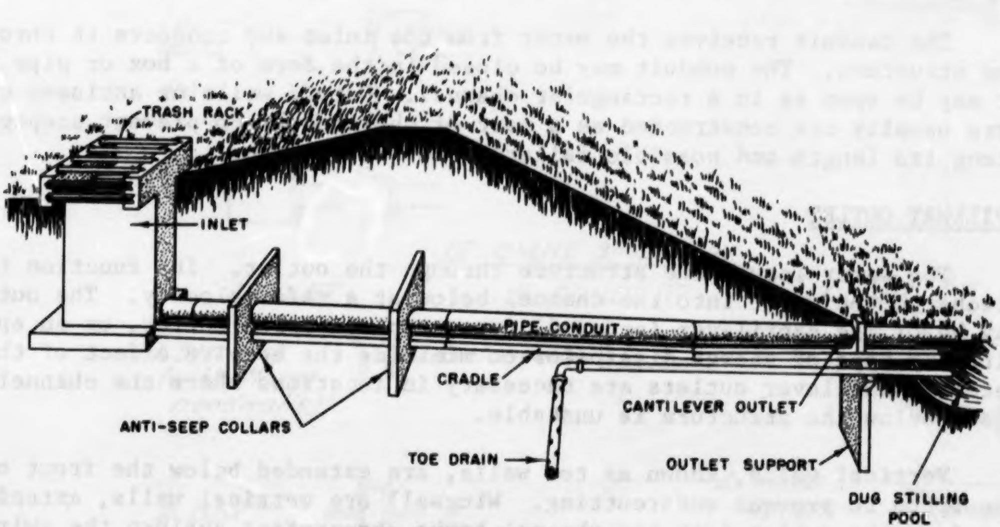

Inlet Channel
Crest
Endwall
Top of Fill
Sidewall
Headwall
Cut-off Wall
Apron
Wingwall
Endsill
Toe Wall
Outlet Channel

BOX INLET DROP SPILLWAY

Figure 6-1 Nomenclature for various parts of drop spillways


WING WALL
FOOTING
STRAIGHT INLET
ANTI-SEEP COLLAR
VERTICAL CURVE SECTION
EXPANSION JOINT
FLOOR
CHANNEL
SIDE WALL
SAF OUTLET
WING WALL
TOE WALL

CHUTE SPILLWAY


TRASH RACK
INLET
PIPE CONDUIT
CRADLE
CANTILEVER OUTLET
ANTI-SEEP COLLARS
TOE DRAIN
OUTLET SUPPORT
DUG STILLING POOL

DROP INLET SPILLWAY

Figure 6-2 Nomenclature for various parts of chute and drop inlet spillways

Various combinations of inlets, conduits, and outlets may be used. For example, a spillway for an earth dam consisting of a drop inlet, pipe conduit, and cantilever outlet is known as a pipe drop inlet spillway with a cantilever outlet. See Figure 6-3.

EMBANKMENT

The embankment directs the flow of water through the spillway. The embankment for a drop spillway or chute generally extends from the spillway to high ground or to a vegetative spillway. In the case of an earth dam (farm pond) the embankment detains and impounds water as well as forces storm flows through the spillway.

SPILLWAY INLET

Water enters the spillway through the inlet, which may be in the form of a box, a weir in a wall, or a culvert-type entrance. The box may be straight or flared, while the wall may be straight, flared, or curved. The culvert-type entrance may be round, square, or rectangular, with a square edge, hood, or flared entrance.

Vertical walls extending into the soil foundations under the inlet are known as cutoff walls. Their main purpose is to prevent water seepage under the structure. Similar walls, extending laterally from the inlet to prevent seepage and erosion around the ends of the structure, are called headwall extensions. These walls also protect against burrowing animals.

SPILLWAY CONDUIT

The conduit receives the water from the inlet and conducts it through the structure. The conduit may be closed in the form of a box or pipe, or it may be open as in a rectangular channel. Cutoff walls or antiseep collars usually are constructed as a part of the conduit to prevent seepage along its length and possible failure from this source.

SPILLWAY OUTLET

The water leaves the structure through the outlet. Its function is to discharge the water into the channel below at a safe velocity. The outlet may be of the cantilever (propped) type, a plain apron outlet, or an apron with any type of energy dissipator to minimize the erosive effect of the water. Cantilever outlets are necessary in locations where the channel grade below the structure is unstable.

Vertical walls, known as toe walls, are extended below the front of the apron to prevent undercutting. Wingwall are vertical walls, extending from the outlet into the channel banks, to protect against the swirling effect of the water as it leaves the structure.

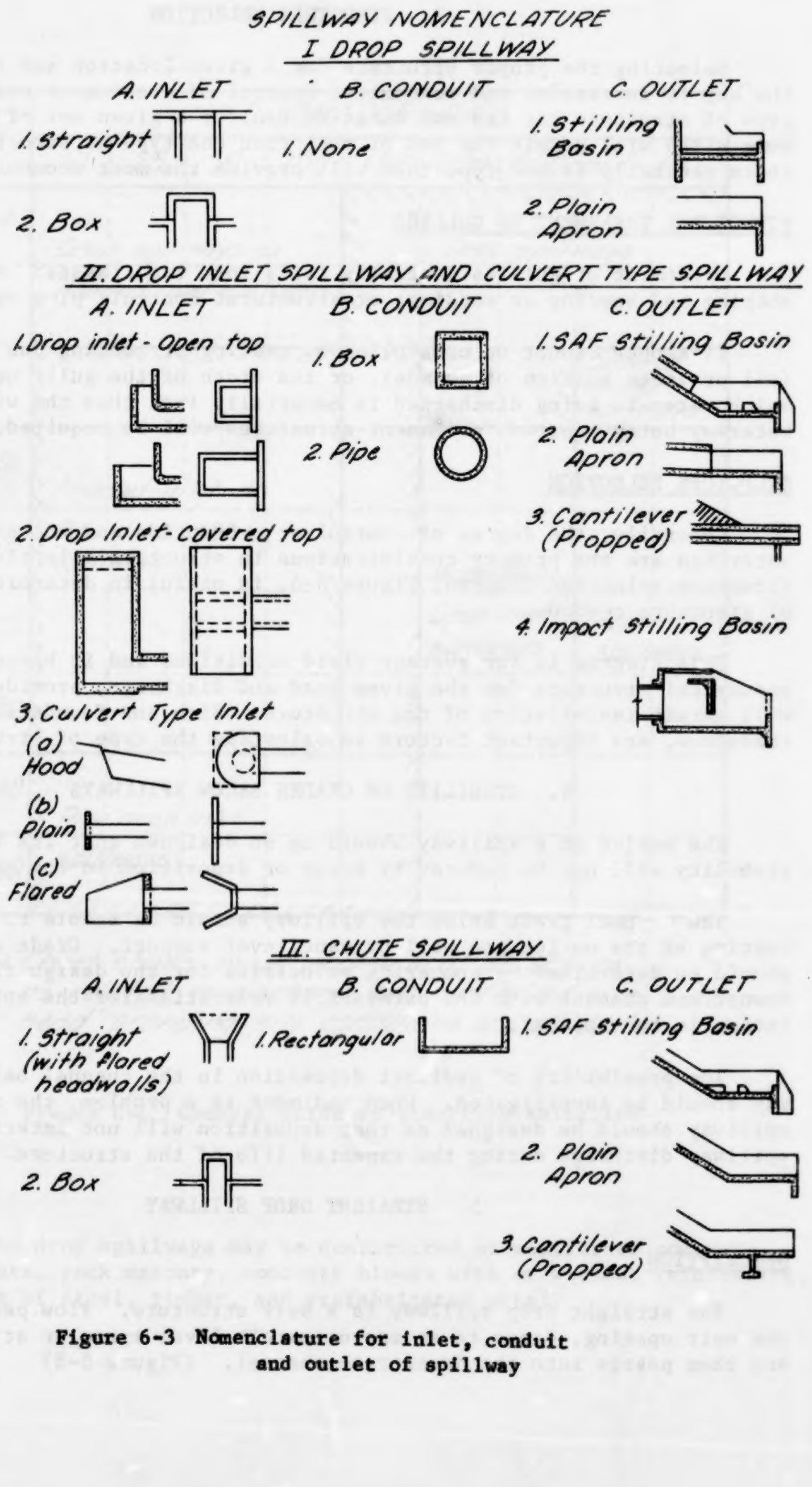

SPILLWAY NOMENCLATURE
I DROP SPILLWAY
A. INLET
B. CONDUIT
C. OUTLET
1. Straight
1. None
1. Stilling Basin
2. Box
2. Plain Apron
II. DROP INLET SPILLWAY AND CULVERT TYPE SPILLWAY
A. INLET
B. CONDUIT
C. OUTLET
1. Drop inlet - Open top
1. Box
1. SAF Stilling Basin
2. Pipe
2. Plain Apron
3. Cantilever (Propped)
2. Drop Inlet - Covered top
4. Impact Stilling Basin
3. Culvert Type Inlet
(a) Hood
(b) Plain
(c) Flared
III. CHUTE SPILLWAY
A. INLET
B. CONDUIT
C. OUTLET
1. Straight (with flared headwalls)
1. Rectangular
1. SAF Stilling Basin
2. Plain Apron
2. Box
3. Cantilever (Propped)

Figure 6-3 Nomenclature for inlet, conduit and outlet of spillway

3. STRUCTURE SELECTION

Selecting the proper structure for a given location and function is the key to successful and economical control of erosion or runoff. Each type of structure has its own range of use for a given set of conditions. Some sites will permit the use of more than one type of structure; however, there generally is one type that will provide the most economical control.

STRUCTURAL TREATMENT OF GULLIES

Treatment of gullies generally falls into two classes: control by shaping and seeding or sodding; or structural control, plus vegetation.

If slopes cannot be controlled by seeding or sodding due to an overfall or steep portion of channel, or the width of the gully or draw into which water is being discharged is materially less than the width of waterway being treated, permanent structures will be required.

STRUCTURE SELECTION

Generally, the degree of control or protection and the size of the watershed are the primary considerations in structure selection. The structure selection diagram, Figure 6-4, is useful in determining the type of structure needed.

This diagram is for average field conditions and is based on the most economical structure for the given head and discharge, provided the site will permit installation of the structure. Site and foundation conditions, therefore, are important factors in selecting the type of structure.

4. STABILITY OF GRADES BELOW SPILLWAYS

The outlet of a spillway should be so designed that its function or stability will not be reduced by scour or deposition in the exit channel.

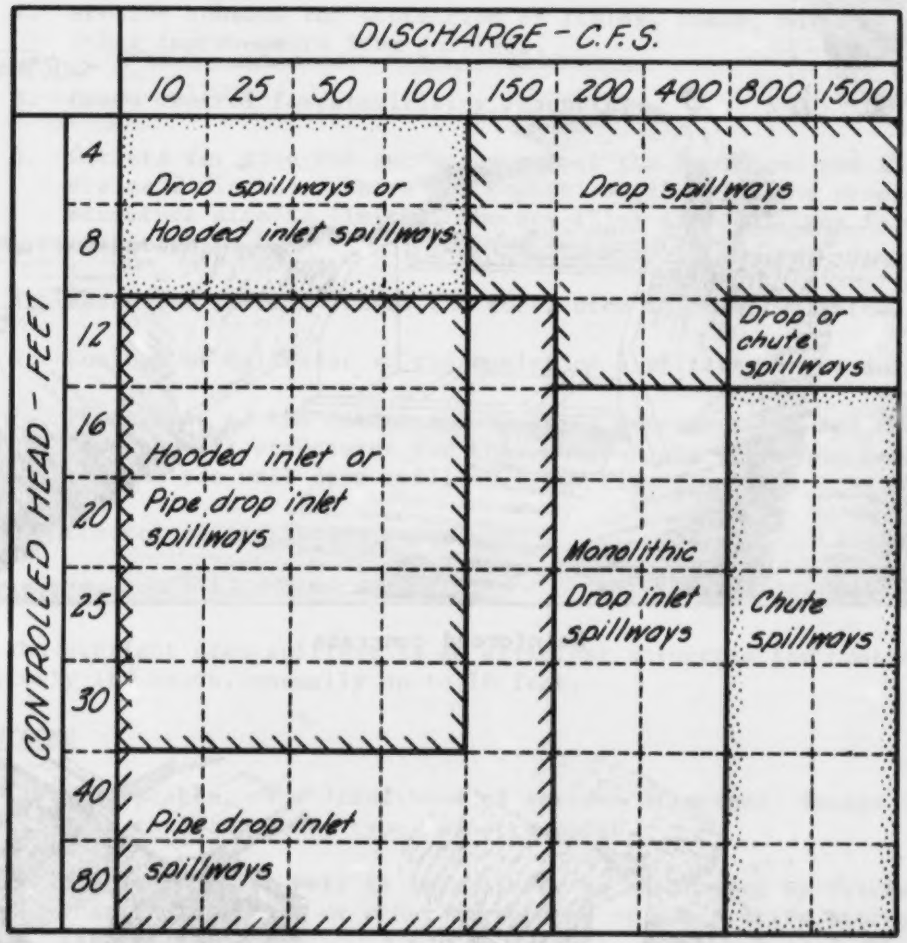
The channel grade below the spillway should be stable to prevent undercutting of the outlet toe wall or cantilever support. Grade stability should be determined by comparing velocities for the design flow in the downstream channel with the permissible velocities for the soils and vegetation in the channel.

The possibility of sediment deposition in the channel below the spillway should be investigated. When sediment is a problem, the outlet of the spillway should be designed so that deposition will not interfere with the spillway discharge during the expected life of the structure.

5. STRAIGHT DROP SPILLWAY

DESCRIPTION

The straight drop spillway is a weir structure. Flow passes through the weir opening, drops to an approximately level apron or stilling basin and then passes into the downstream channel. (Figure 6-5)

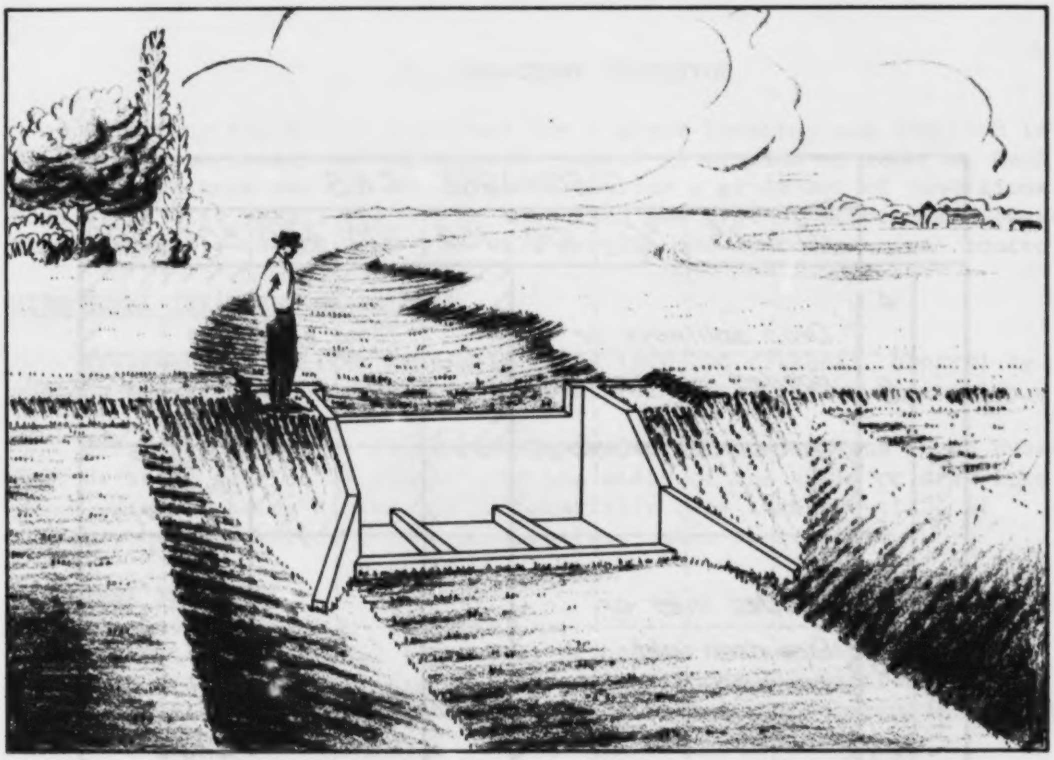


Note: Chart shows most economical structure as related to discharge and controlled head providing site conditions are adequate.

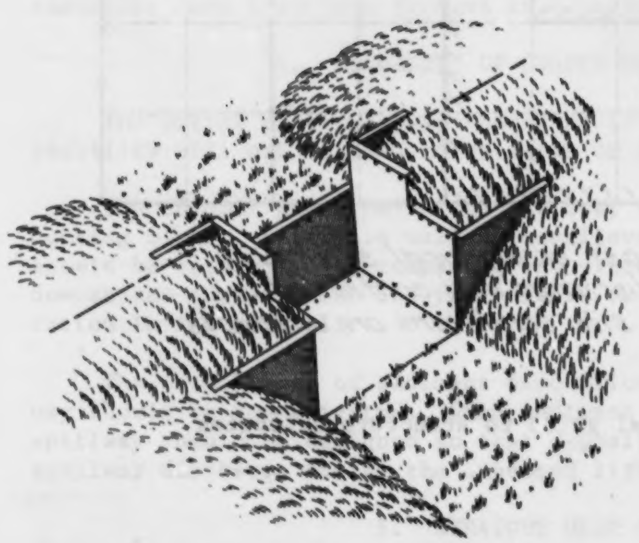
Figure 6-4 General guide to structure selection

MATERIALS

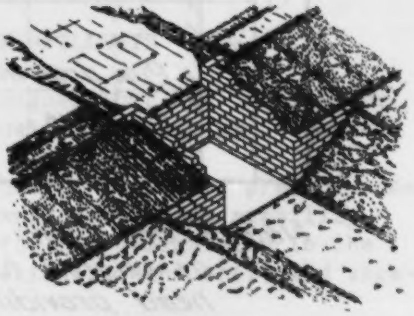
Straight drop spillways may be constructed of reinforced concrete, plain concrete, rock masonry, concrete blocks with or without reinforcing, sheet piling of steel, timber, and prefabricated metal.



Reinforced concrete



Prefabricated metal



Concrete block

Figure 6-5 Straight drop spillways

FUNCTIONAL USE

1. Grade stabilization in lower reaches of waterways and outlets.
2. Erosion control for protection of fields, roads, buildings and other improvements from gullies.
3. Grade control for stabilizing channels.
4. Outlets for tile and surface water at the upper end and along drainage ditches. Where the channel width below the proposed structure site is limited, the box inlet drop spillway is more effective.
5. Reservoir spillway where the total drop is relatively low.
6. Control of tailwater at the outlet of a spillway or conduit.
7. Protection of the outlet end of grass waterways and sod chutes. Low headwall structures for this purpose are sometimes referred to as a toe wall drop spillway. See Figure 6-9.
8. Control of irrigation water.

ADAPTABILITY

The straight drop spillway is an efficient structure for controlling relatively low heads, normally up to 10 feet.

ADVANTAGES

1. Very stable. The likelihood of serious structural damage is less than for other types of structures.
2. The rectangular weir is less likely to be clogged by debris than the openings or other structures of comparative discharge capacities.
3. They are relatively easy to construct. The concrete block type can be built with farm labor, while the reinforced concrete or steel sheet piling type usually requires the services of a contractor.

LIMITATIONS

1. It is more costly than some other types of structures where the required discharge capacity is less than 100 c.f.s. and the total head or drop is greater than 10 feet.
2. It is not a favorable structure where temporary spillway storage is needed to obtain a large reduction in discharge.

3. A stable grade below the structure is essential.

SITE SELECTION

Proper site selection is dependent upon adequate field surveys and foundation data. Attention must be given to changed water elevations caused by the proposed structures as they might affect adjacent highways and their drainage structures, railroads, pipelines and other improvements or properties.

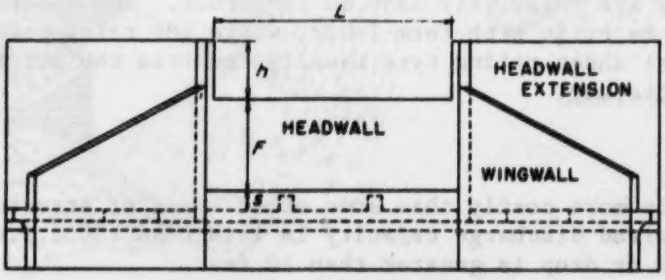
For grade control drops with definite approach channels, the site should be selected so that the spillway can be located on a reasonably straight section of channel, with no upstream or downstream curves within at least 100 feet of the structure. It often will be desirable to straighten the channel alignment above and below the spillway so that it merges smoothly with the existing channel. Poor alignment may result in a reduction in discharge capacity and excessive scour of the embankment and channel banks. There should be no channel restrictions or obstacles in the approach channel that would interfere with the design flow entering the spillway inlet.

The site selected should provide an adequate foundation for the spillway. The foundation material must have the required supporting strength, resistance to sliding and piping, and be reasonably homogeneous so as to prevent uneven settlement of the structure.

DESIGN

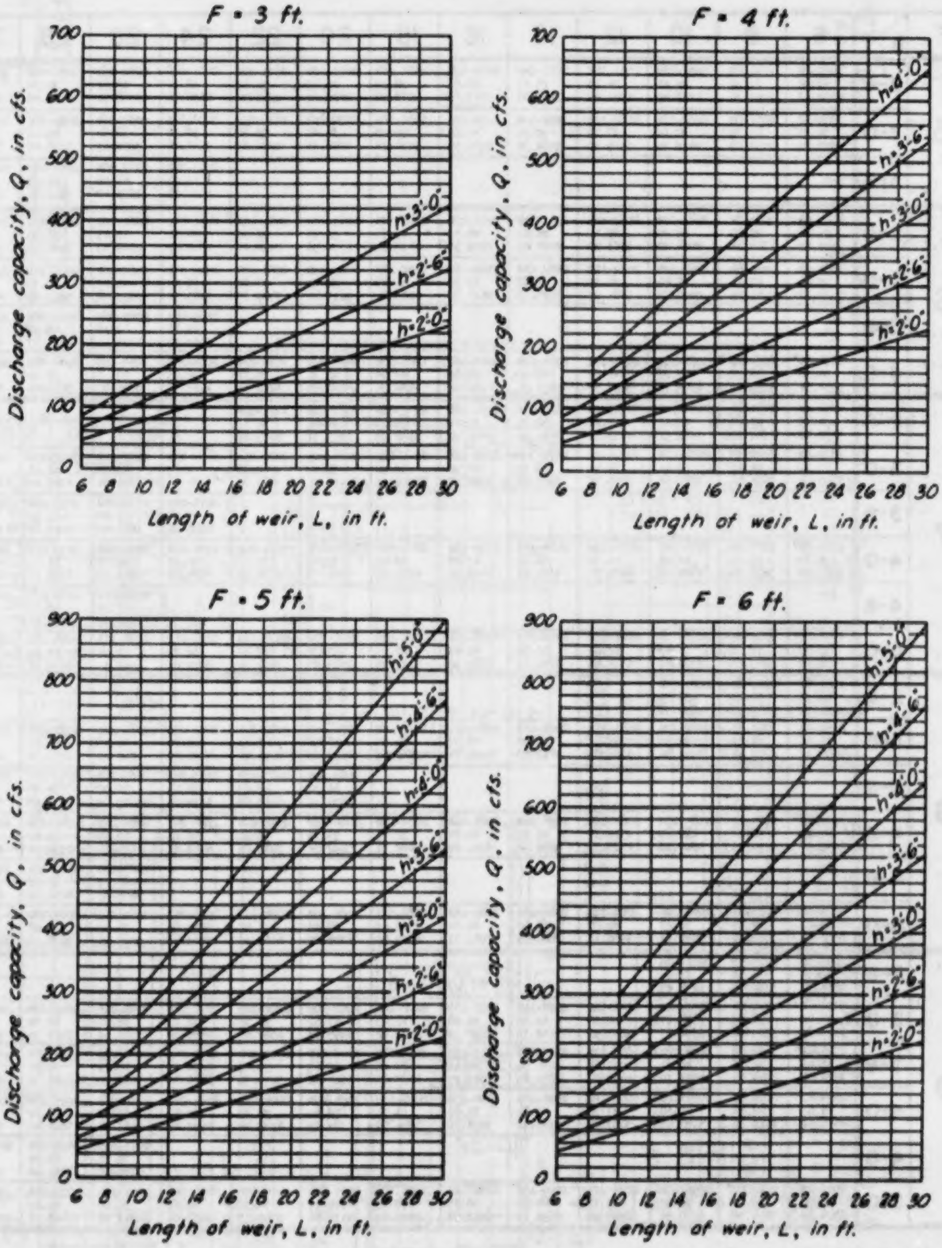
Planning and design of straight drop spillways normally require the assistance of an engineer. Local personnel may be trained to plan and install small drop spillway structures when standard plans are available.

Measurement locations for symbols F (overfall in feet), h (depth of weir in feet), s (depth of stilling pool in feet), and L (length of weir in feet) are shown in Figure 6-6.



DOWNSTREAM ELEVATION

Figure 6-6 Symbols for straight drop spillway



Note: h = total depth of weir, in feet (including freeboard)

F = net drop from crest to top of transverse sill, in feet

(For type B drops keep h ÷ F less than 0.75)

$$Q = \frac{3.1\ L h^{3/2}}{(1.10 + 0.01\ F)}$$

Reference — ES65
Sec. II N.E.H.

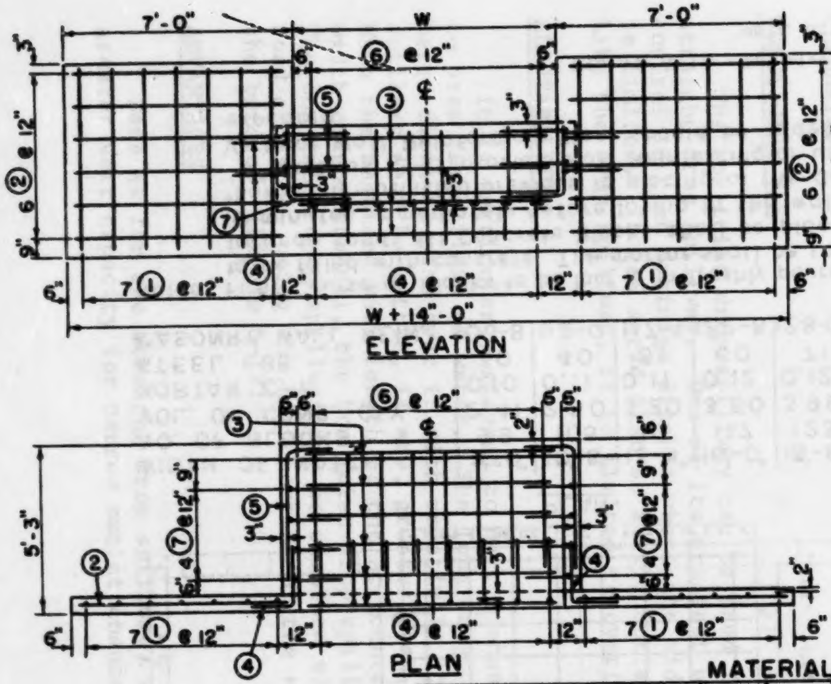
Figure 6-7 Weir capacity for straight drop spillways

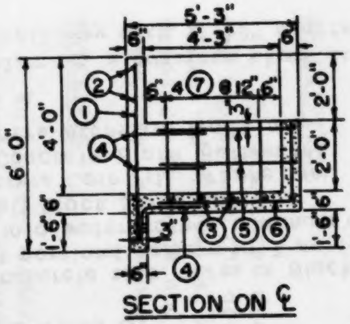
F	h \ L	6	8	10	12	14	16	18	20	22	24	26	28	30
5	2-6	2051-6B 19.98 1400.47	2051-8B 21.32 1591.56	2051-10B 22.66 1833.29	2051-12B 24.13 1757.87	2051-14B 25.47 1882.85	2051-16B 26.81 1947.69	2051-18B 28.15 2148.58	2051-20B 29.49 2206.85	2051-22B 30.83 2376.90	2051-24B 32.17 2456.30	2051-26B 33.51 2548.91	2051-28B 34.84 2708.46	2051-30B 36.18 2923.96
	3-0	2052-6B 24.36 1975.81	2052-8B 25.78 2167.93	2052-10B 27.20 2416.75	2052-12B 28.79 2313.39	2052-14B 30.21 2464.78	2052-16B 31.63 2559.55	2052-18B 33.05 2720.18	2052-20B 34.46 2830.36	2052-22B 35.88 2966.63	2052-24B 37.30 3117.16	2052-26B 38.72 3230.65	2052-28B 40.14 3368.08	2052-30B 41.56 3531.59
	3-6										2053-24B 43.06 3457.55	2053-26B 44.56 3655.43	2053-28B 46.05 3812.61	2053-30B 47.55 4023.02
6	2-6	2061-6B 21.08 1601.43	2061-8B 22.50 1767.24	2061-10B 23.92 2034.92	2061-12B 25.49 1973.92	2061-14B 26.91 2092.83	2061-16B 28.33 2206.57	2061-18B 29.75 2433.87	2061-20B 31.17 2532.38	2061-22B 32.59 2734.61	2061-24B 34.01 2830.03	2061-26B 35.43 2986.35	2061-28B 36.85 3167.85	2061-30B 38.27 3405.80
	3-0	2062-6B 25.64 2103.37	2062-8B 27.14 2283.59	2062-10B 28.64 2592.72	2062-12B 30.33 2484.08	2062-14B 31.83 2626.73	2062-16B 33.33 2814.70	2062-18B 34.83 3023.87	2062-20B 36.33 3111.19	2062-22B 37.83 3309.80	2062-24B 39.33 3485.35	2062-26B 40.83 3622.38	2062-28B 42.33 3817.95	2062-30B 43.83 4055.17
	3-6										2063-24B 45.77 3961.17	2063-26B 47.36 4175.51	2063-28B 48.96 4424.57	2063-30B 50.55 4660.84
	4-0	2064-6B* 36.70 3894.86	2064-8B 38.38 3953.83	2064-10B 40.05 3965.15	2064-12B 42.02 3884.54	2064-14B 43.69 4033.21	2064-16B 45.36 4186.48	2064-18B 47.04 4434.64	2064-20B 48.71 4544.86	2064-22B 50.38 4802.44	2064-24B 52.05 4967.94	2064-26B 53.73 5392.81	2064-28B 55.40 5511.74	2064-30B 57.07 5798.13
7	2-6	2071-6B 24.15 1770.40	2071-8B 25.64 1962.20	2071-10B 27.15 2281.97	2071-12B 28.81 2133.03	2071-14B. 30.33 2291.06	2071-16B 31.84 2494.10	2071-18B 33.35 2630.02	2071-20B 34.86 2795.37	2071-22B 36.37 2983.80				
	3-0	2072-6B 27.21 2305.84	2072-8B 28.81 2594.80	2072-10B 30.41 2971.44	2072-12B 32.20 2768.75	2072-14B 33.79 2985.86	2072-16B 35.39 3108.17	2072-18B 36.98 3296.11	2072-20B 38.58 3456.31	2072-22B 40.17 3683.76	2072-24B 41.77 3934.24	2072-26B 43.37 4104.64	2072-28B 44.96 4308.07	2072-30B 46.56 4638.52
	3-6										2073-24B 47.94 4606.39	2073-26B 49.60 4881.46	2073-28B 51.29 5103.44	2073-30B 52.97 5389.76
	4-0	2074-6B* 38.72 3517.19	2074-8B 40.49 3818.79	2074-10B 42.26 4322.54	2074-12B 44.34 4060.57	2074-14B 46.11 4304.97	2074-16B 47.88 4435.01	2074-18B 49.65 4679.42	2074-20B 51.41 4941.73	2074-22B 53.18 5356.99	2074-24B 54.95 5614.07	2074-26B 56.72 5862.35	2074-28B 58.49 6158.87	2074-30B 60.25 6465.89
	4-6											2075-26B 64.60 6668.62	2075-28B 66.44 6902.07	2075-30B 68.29 7270.07
	5-0	2076-6B* 51.60 5758.48	2076-8B* 53.52 6063.63	2076-10B 55.45 6506.82	2076-12B 57.83 6374.43	2076-14B 59.76 6630.05	2076-16B 61.69 6866.32	2076-18B 63.61 7137.31	2076-20B 65.54 7383.82	2076-22B 67.47 7591.14	2076-24B 69.39 8021.24	2076-26B 72.01 7986.59	2076-28B 73.93 8195.88	2076-30B 75.86 8441.24
8	2-6	2081-6B 28.52 2686.72	2081-8B 30.11 2580.95	2081-10B 31.70 2894.57										
	3-0	2082-6B 30.00 2606.59	2082-8B 31.67 2933.42	2082-10B 33.35 3393.86	2082-12B 35.22 3166.00	2082-14B 36.90 3418.33	2082-16B 38.57 3621.84	2082-18B 40.24 3842.53	2082-20B 41.92 4035.69	2082-22B 43.59 4296.86	2082-24B 45.26 4796.48	2082-26B 46.93 4846.29	2082-28B 49.45 4347.78	2082-30B 51.12 4800.91
	3-6								2083-20B 46.92 4835.15	2083-22B 48.69 5148.68	2083-24B 50.45 5314.69	2083-26B 52.22 5673.64	2083-28B 54.83 5596.68	2083-30B 56.59 5968.93
	4-0	2084-6B* 40.29 3942.57	2084-8B 42.14 4290.39	2084-10B 43.99 4667.86	2084-12B 46.17 4368.02	2084-14B 48.02 4659.58	2084-16B 49.87 5001.22	2084-18B 51.71 5440.11	2084-20B 53.56 5692.84	2084-22B 55.41 5976.66	2084-24B 57.26 6443.37	2084-26B 59.96 6131.76	2084-28B 61.81 6355.72	2084-30B 63.66 6667.19
	4-6											2085-26B 67.43 7848.31	2085-28B 69.36 8050.62	2085-30B 71.28 8319.20
	5-0	2086-6B* 54.03 6730.94	2086-8B* 56.05 7031.80	2086-10B 58.07 7396.94	2086-12B 60.57 7400.43	2086-14B 62.59 7687.55	2086-16B 64.61 7941.71	2086-18B 66.63 8355.59	2086-20B 68.66 8708.75	2086-22B 71.61 8487.16	2086-24B 73.64 8903.10	2086-26B 75.66 9273.94	2086-28B 77.68 9698.10	2086-30B 79.70 10130.08
9	2-6	2091-6B 33.56 2886.57	2091-8B 35.34 3136.72	2091-10B 37.09 3438.05										
	3-0	2092-6B 35.02 3165.83	2092-8B 36.79 3375.92	2092-10B 38.77 3596.87	2092-12B 40.54 3833.91	2092-14B 42.31 4148.74	2092-16B 44.08 4398.32	2092-18B 45.85 4672.12	2092-20B 47.62 4995.58	2092-22B 50.50 4669.28	2092-24B 52.27 4889.04	2092-26B 54.03 5168.69	2092-28B 55.80 5478.30	2092-30B 57.57 5825.39
	3-6	2093-6B* 36.91 3865.64	2093-8B 38.76 4082.43	2093-10B 40.61 4343.10	2093-12B 42.74 4405.33	2093-14B 44.59 4659.63	2093-16B 46.44 4949.25	2093-18B 48.28 5268.80	2093-20B 50.13 5668.76	2093-22B 53.09 5879.76	2093-24B 54.94 5506.79	2093-26B 56.79 5916.74	2093-28B 58.64 6187.86	2093-30B 60.48 6559.76
	4-0	2094-6B* 41.81 4376.48	2094-8B 43.74 4728.70	2094-10B 45.68 5193.83	2094-12B 47.95 5067.83	2094-14B 49.88 5335.07	2094-16B 51.81 5644.16	2094-18B 53.74 6034.57	2094-20B 56.80 5782.65	2094-22B 58.73 6148.78	2094-24B 60.66 6387.49	2094-26B 62.59 6602.44	2094-28B 64.52 7082.40	2094-30B 66.46 7406.17
	4-6											2095-26B 70.76 8572.17	2095-28B 72.79 8964.40	2095-30B 74.81 9317.86
	5-0	2096-6B* 55.98 7304.69	2096-8B* 58.02 7844.56	2096-10B 60.12 8305.86	2096-12B 62.78 8886.26	2096-14B 64.85 8639.17	2096-16B 66.93 9017.95	2096.18B 69.03 9353.63	2096-20B 72.27 9178.51	2096-22B 74.37 9509.13	2096-24B 76.48 9887.44	2096-26B 78.58 10311.98	2096-28B 80.69 10693.95	2096-30B 82.79 10950.97

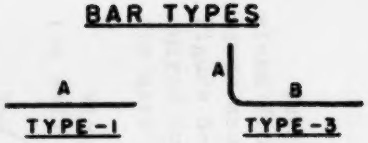
(1) Notes: Drawing No., cu. yds of concrete, and lbs.. of reinforcing steel are listed vertically in order for each size. Each drawing number shall be prefixed with the letters E. S.

(2) *The ratio of L ÷ h is less than 2.0 for these values. Correction for hydraulic losses due to end contractions must be considered in the solution of the weir formula, for discharge capacity, before these drop spillways can be applied.

Figure 6-8 Standard plans: series "B" reinforced concrete drop spillways schedule showing drawing number, cubic yards of concrete, and pounds of reinforcing steel


7'-0"
W
7'-0"
⑥ @ 12"
6"
⑤
③
℄
3"
6 ② @ 12"
6'-0"
9"
⑦
④
7 ① @ 12"
12"
④ @ 12"
W + 14"-0"
ELEVATION
6"6"
5"5"
2"
5'-3"
9"
4 ⑦ @12"
3"
PLAN


5'-3"
6"
4'-3"
6"
4 ⑦ @ 12"
②
①
④
6'-0"
4'-0"
2'-0"
2'-0"
6"
1'-6"
3"
③
⑤
⑥
SECTION ON ℄

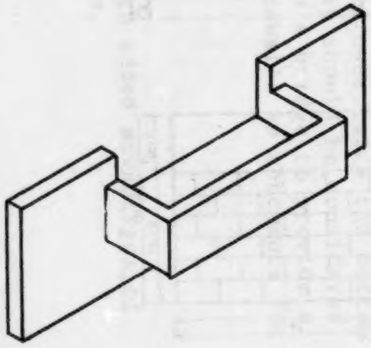

BAR TYPES
A
TYPE-1
A
B
TYPE-3

BAR SCHEDULE

MARK	TYPE	QUAN.	A	B
1	1	14	5'-6"	
2	1	12	6'-6"	
3	1	8	W-6"	
4	3		1'-9"	1'-3"
5	3	4	4'-3"	1'-9"
6	3		4'-2"	2'-1"
7	3	8	1'-9"	2'-0"

MATERIALS SCHEDULE

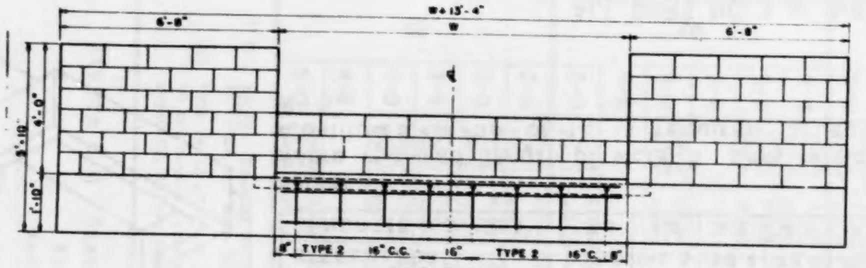
WIDTH (W) (FT.)	8	10	12	14	16	18	20	22	24
NO. OF MARK 4 BARS	12	14	16	18	20	22	24	26	28
NO. OF MARK 6 BARS	8	10	12	14	16	18	20	22	24
STEEL (LBS.)	133.5	146.5	159.4	172.4	185.4	198.3	211.3	224.3	237.3
CONCRETE (CU. YDS.)	3.3	3.6	3.9	4.3	4.6	4.9	5.2	5.6	5.9



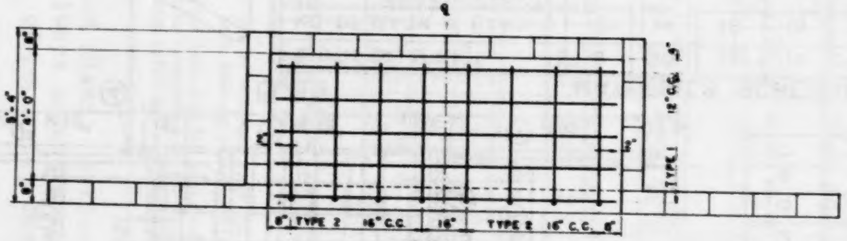
Notes:
Where required length of Mark 3 bars is not available, two or three spliced bars may be substituted. A lap of 12" is required at each splice. The total spliced length shall equal W-6".

ALL BARS NO. 3 or 3/8" ø

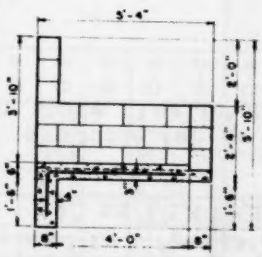
Figure 6-9 Standard plan for a reinforced concrete toe wall with 2'-0" overfall drop spillway


W+13'-4"
6'-8"
W
6'-8"
℄
3'-10"
4'-0"
1'-10"
8"
TYPE 2
16" C.C.
16"
TYPE 2
16" C.
8"

ELEVATION


℄
8"
5'-4"
4'-0"
8"
12" C.C.
TYPE 1
12"
8"
TYPE 2
16" C.C.
16"
TYPE 2
16" C.C.
8"

PLAN


5'-4"
3'-10"
1'-6"
6"
2'-0"
2'-4"
1'-6"
5'-10"
4"
8"
4'-0"
8"

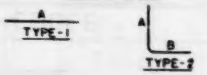
SECTION ON ℄

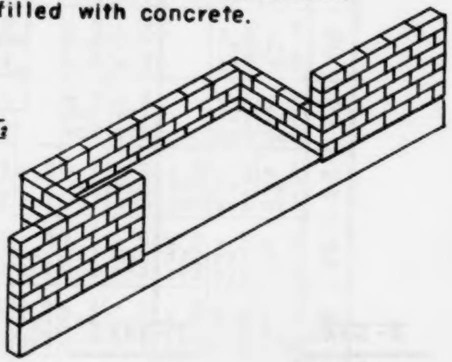
WIDTH OF NOTCH	8'-0"	10'-8"	13-4"	16'-0"	18'-8"	21-4"	24'-0"
NO. OF BLOCKS	99	105	111	117	123	129	135
VOL. OF CONC. C. Y.	2.41	2.80	3.20	3.60	3.99	4.38	4.78
MORTAR C. Y.	0.10	0.11	0.11	0.12	0.12	0.13	0.14
STEEL LBS.	30	40	51	60	71	81	92
MASONRY WALL REIN.	106-8	112-0	117-4	122-8	128-0	133-4	138-8

BAR SCHEDULE				
TYPE	SIZE	QUAN.	A	B
1	#3		W-4"	
2	#3		4'-4"	1'-4"

MASONRY WALL REINFORCEMENT
9 Gage galvanized wire. Available in 4", 6", 8", 10" and 12" widths. Reinforcing placed between each course of blocks after cores have been filled with concrete.

BAR-TYPES


A
TYPE-1
A
B
TYPE-2



Notes: First Course of Blocks to be laid 2" in freshly poured concrete slab. Cores in Blocks to be filled with concrete. The mortar shall be 1 part portland cement to 3 parts torpedo sand. All Concrete Blocks shall be placed in a water bath a minimum of 10 minutes immediately before laying in the wall. All block cores shall be thoroughly sprinkled previous to placing of the Concrete Core Fill. Where Weir "W" exceeds 12'-0" provide Wall Reinforcing or use Concrete Block Buttresses. Vertical Wall Reinforcing Steel should be added where excessive loads are expected.

Figure 6-10 Standard plan for a concrete block toe wall drop spillway with 1'-10" overfall

Weir capacities for low-overfall straight drop spillways can be determined from Figure 6-7 for various combinations of F, h, and L. Standard plans are available for the Series "B" reinforced concrete drop spillways. Figure 6-8 can be used for estimating cost of these structures. The required cubic yards of concrete and pounds of reinforcing steel are shown for each size.

Figure 6-9 is an example of a standard plan for a reinforced concrete toe wall drop spillway. Concrete block toe walls are shown in Figure 6-10.

The earthfill embankment should conform to State Standards and Specifications.

6. BOX INLET DROP SPILLWAY

DESCRIPTION

The box inlet drop spillway structure is a rectangular box open at the top and at the downstream end. Storm runoff, directed to the box by dikes and headwalls, enters over the upstream end and two sides. The flow drops to an apron and leaves through the open downstream end. An outlet structure is attached to the downstream end of the box. (Figure 6-11)

MATERIALS

Reinforced concrete is best. However, reinforced concrete block structures can be used for low overfalls (3 feet or less) and narrow channels.

FUNCTIONAL USE

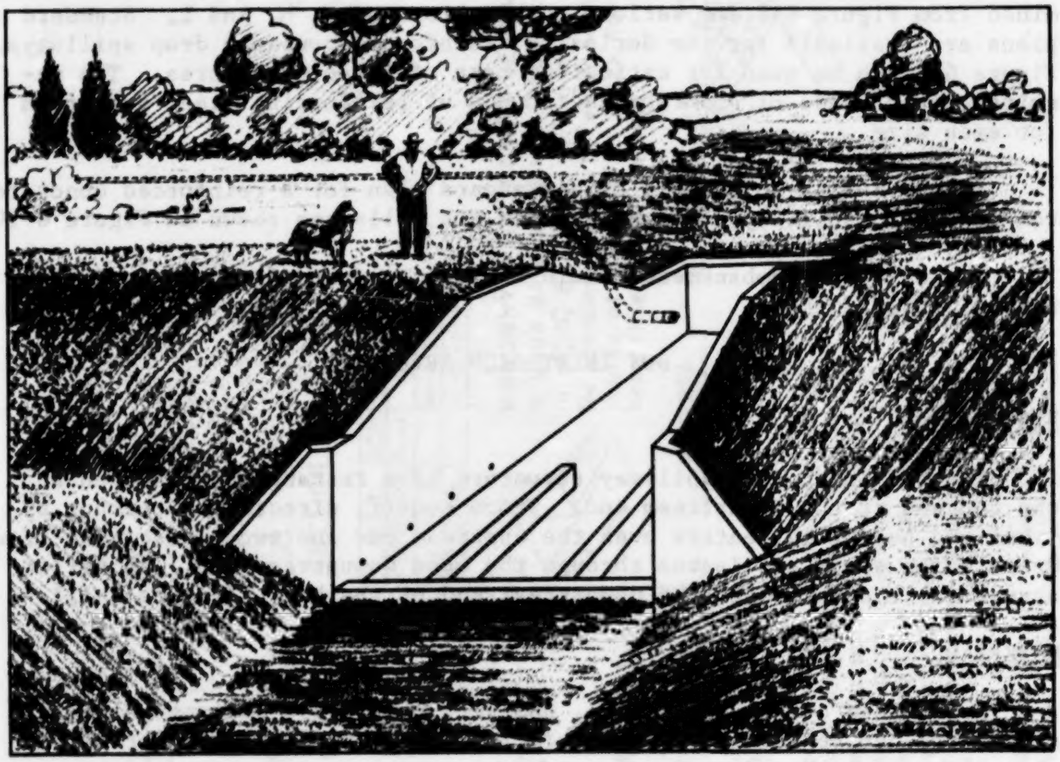
The box inlet drop spillway can be used for the same purposes as a straight drop spillway. One of its greatest uses is for grade and erosion control in open drainage ditches where the width of channel at the outlet is limited. It can serve also as a tile outlet at the head of the ditch. Like the drop spillway, it is limited to overfall heights up to 10 feet.

ADAPTABILITY

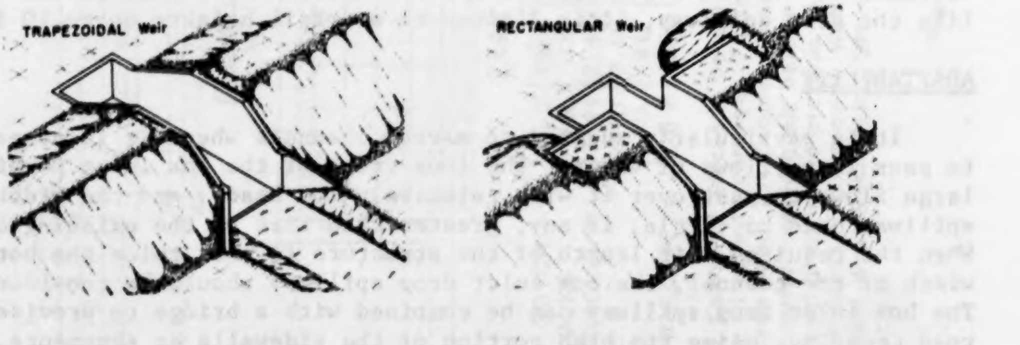
It is particularly adapted to narrow channels where it is necessary to pass large flows of water. The long crest of the box inlet permits large flows to pass over it with relatively low heads, and the width of the spillway need be little, if any, greater than that of the existing channel. When the required weir length of the structure is over twice the bottom width of the channel, the box inlet drop spillway should be considered. The box inlet drop spillway can be combined with a bridge to provide a road crossing, using the high portion of the sidewalls as abutments for the bridge. (Figure 6-12)

ADVANTAGES

Same as for the straight drop spillway, with added advantages of greater weir capacity for narrow outlet channels.



Reinforced concrete


TRAPEZOIDAL Weir
RECTANGULAR Weir

Types of weirs for box inlet drop spillways

Figure 6-11 Box inlet drop spillway

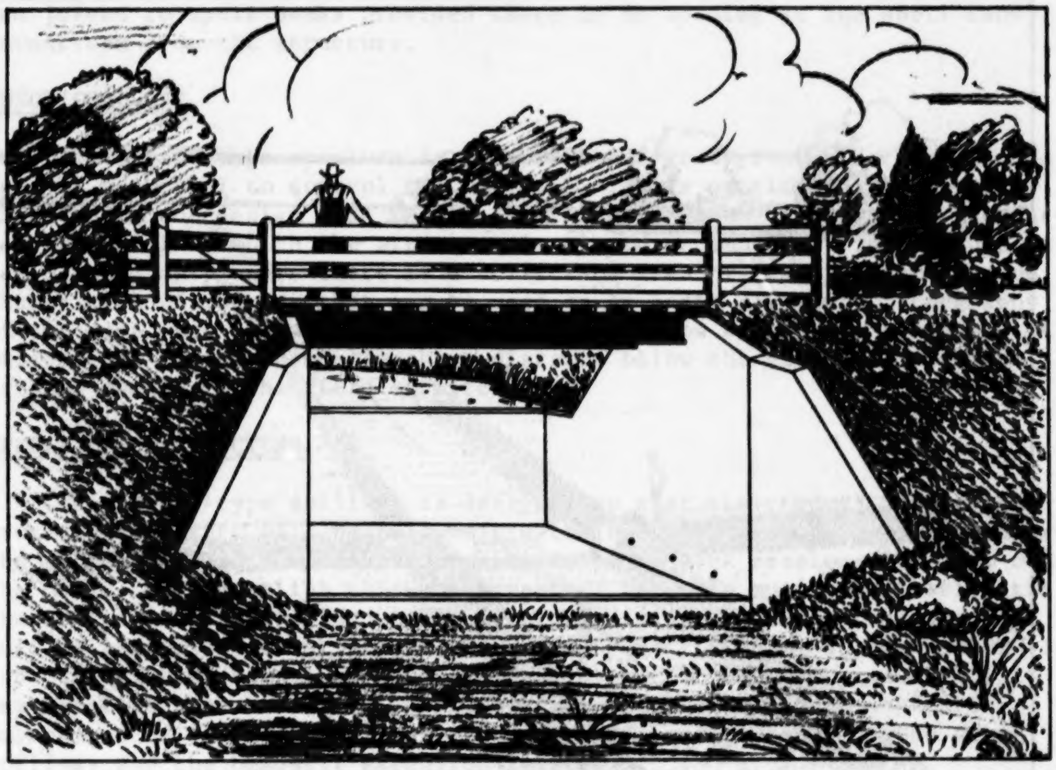


Figure 6-12 Box-inlet drop spillway with a bridge over the top

LIMITATIONS

Same as for straight drop spillways.

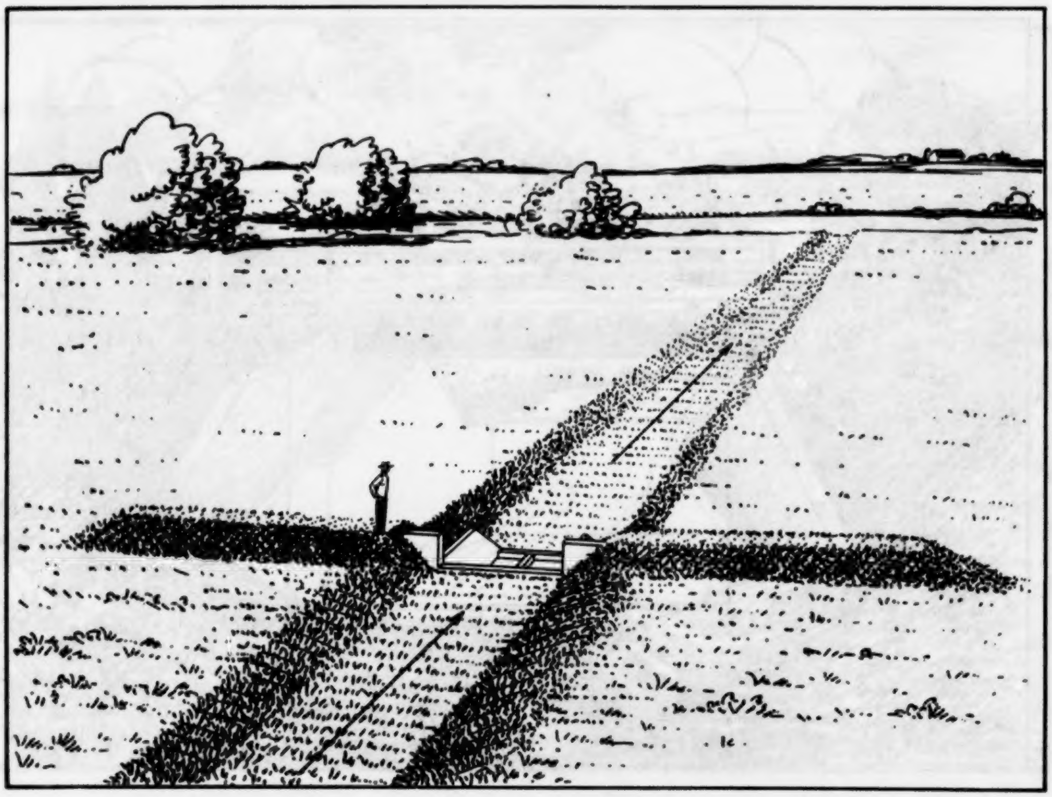
DESIGN

The complexity of design and layout of box inlet drop spillways requires the assistance of an engineer.

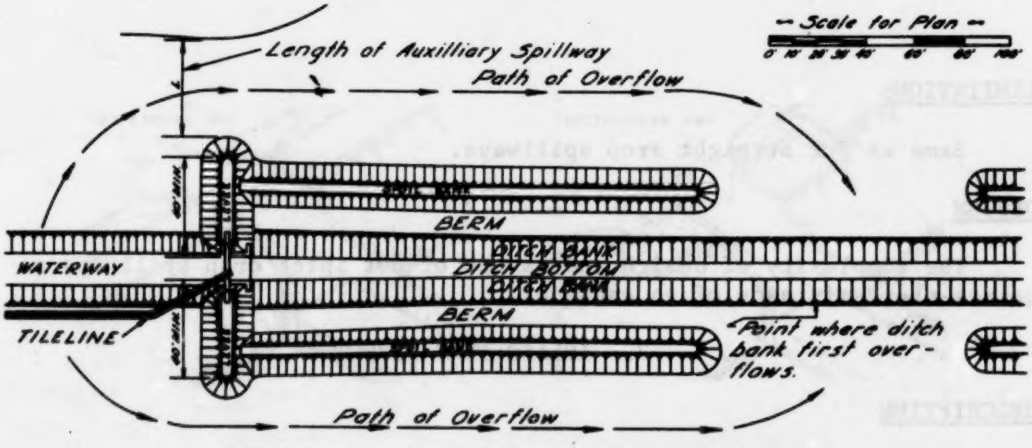
7. ISLAND-TYPE STRUCTURE

DESCRIPTION

The island-type spillway uses a drop spillway in the channel with auxiliary earth spillways for carrying excess flows around the structure. Either the straight drop spillway or the box inlet drop spillway can be used. (Figure 6-13) To prevent washing around the structure, dikes extending each way from the structure must be provided. In some cases the dikes



Island-type spillway showing embankments extending out from headwall extensions


Scale for Plan
0' 10' 20' 30' 40' 60' 80' 100'
Length of Auxilliary Spillway
Path of Overflow
60' MIN.
SPOIL BANK
BERM
WATERWAY
DITCH BANK
DITCH BOTTOM
DITCH BANK
BERM
TILELINE
60' MIN.
SPOIL BANK
Point where ditch bank first overflows.
Path of Overflow

Plan view of layout for island-type spillway with levees parallel to the ditch to force overflow some distance below structure

Figure 6-13 Island-type spillways

are joined to spoil banks provided there is an opening in the spoil bank downstream from the structure.

FUNCTIONAL USE

The island-type spillway is adaptable for grade control or use at the head of a channel to control the overfall. It is particularly adapted to sites where the design peak runoff is greater than the capacity of the outlet channel into which the structure is placed or empties. This structure can be used only where there is a sufficient area of nearly level land on either side of the dam that can be used as an earth spillway. Topography of the area must be such that the path of overflow around the structure will return to the channel a short distance below the structure without causing damage to the field or ditchbanks.

OPERATION OF STRUCTURE

The island-type spillway is designed so that the channel downstream from the structure will be full before the overflow around the dam reenters the channel. This reduces the possibilities of bank erosion from flow over the bank. To accomplish this, the crest of the weir must be set below the crest of the earth spillway. The vertical distance between these points must be sufficient to provide a weir notch capacity equal to the bank-full capacity of the channel at the place where the flow from the earth spillway reenters the channel. Large flows will then pass around the earth embankment of the drop spillway, forming an island composed of the drop spillway and the headwall extension levees.

The channel above the structure at the point where overflow begins must have the same capacity as the channel below the structure. In this way, the discharge from the channel above the structure will fill the channel below it before the banks at the structure are overtopped and flow is directed to the earth spillway. Also, the structure should be so proportioned that the channel banks will overflow near the structure as soon as the channel capacity flow has been reached.

ADVANTAGES

It permits the use of a drop spillway having less capacity than the peak runoff for the design storm.

LIMITATIONS

It often requires the construction of earth spillways in cropland areas. Therefore, it is harder to maintain the correct grade and elevation.

DESIGN

The layout and design of the island-type structure requires the assistance of an engineer.

8. DROP BOX (CULVERT INLET)

DESCRIPTION

A drop box is a rectangular box inlet drop spillway placed at the upstream end of a culvert. It may be built as an integral part of a new culvert, or it can be fastened by dowel bars to the upstream headwall of an existing culvert. Storm runoff is directed to the box by the highway fill. (Figure 6-14)

FUNCTIONAL USE

Drop boxes are used to control grades above culverts in either natural or constructed channels. They may serve as an outlet for tile drains. Cattle ramps can be incorporated into the design of the box when the culvert is used as a cattle pass. See Figure 6-15 - upper sketch. The drop box is very effective for erosion control in highway ditches as shown in Figure 6-15 - lower sketch.

MATERIALS

Reinforced concrete is the best and most commonly used material for constructing drop boxes. In some cases, concrete blocks or prefabricated metal can be used. Material used should be consistent with the expected remaining life of the culvert to which the drop box is to be attached. The addition of a headwall will be required where none exists.

ADVANTAGES

It is one of the most economical structures for controlling overfalls because the existing culvert and highway embankment replace the outlet portion of the typical drop spillway. It has the advantage of the box inlet drop spillway in that the weir length can be fitted to a narrow waterway.

LIMITATIONS

It requires the availability of structurally sound road culverts. The structure is often attached to a road culvert which is the property of a roadway governing body and, therefore requires its permission. They may not allow maintenance and control on the part of the landowner.

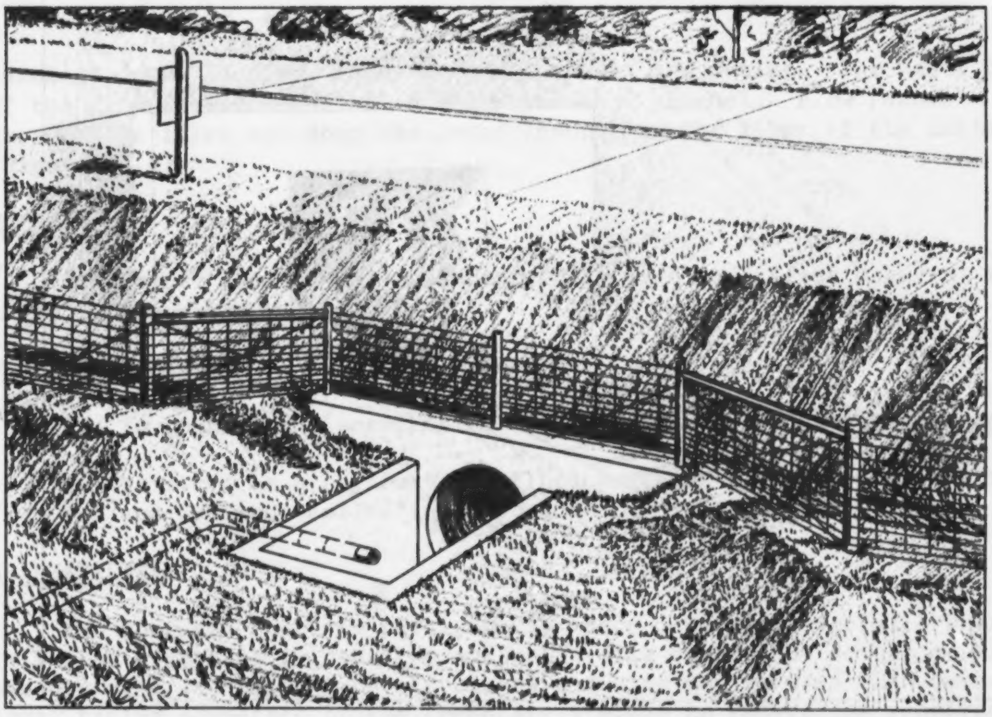
DESIGN

The design and layout of a drop box requires the assistance of an engineer.

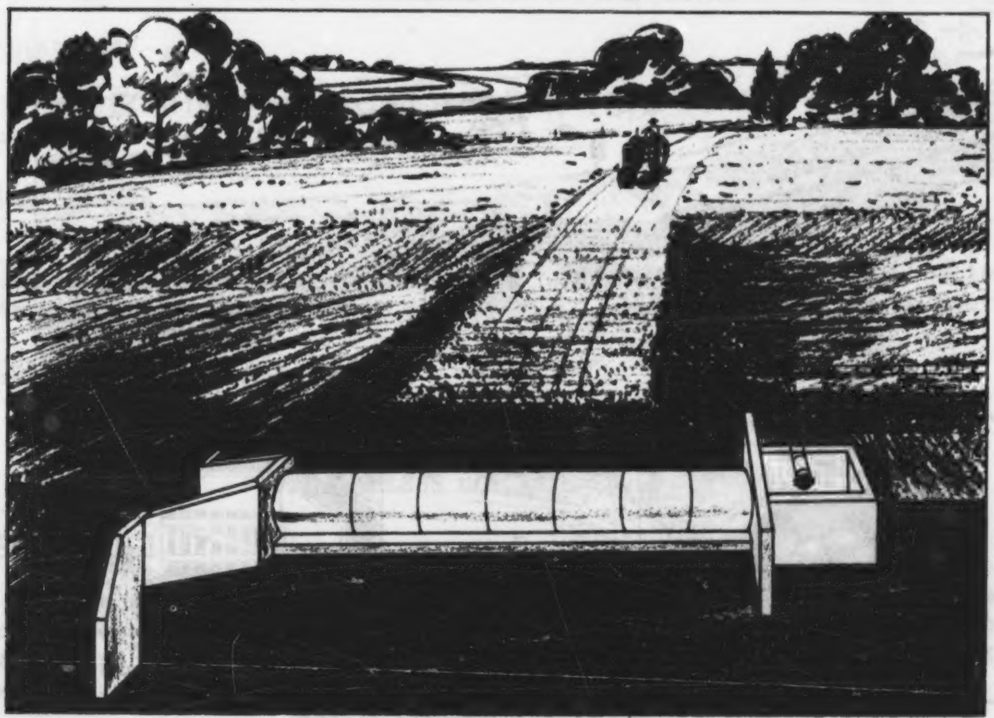
9. CONCRETE CHUTE SPILLWAY

DESCRIPTION

A chute spillway is an open channel with a steep slope in which flow is carried at supercritical velocities. It usually consists of an inlet,

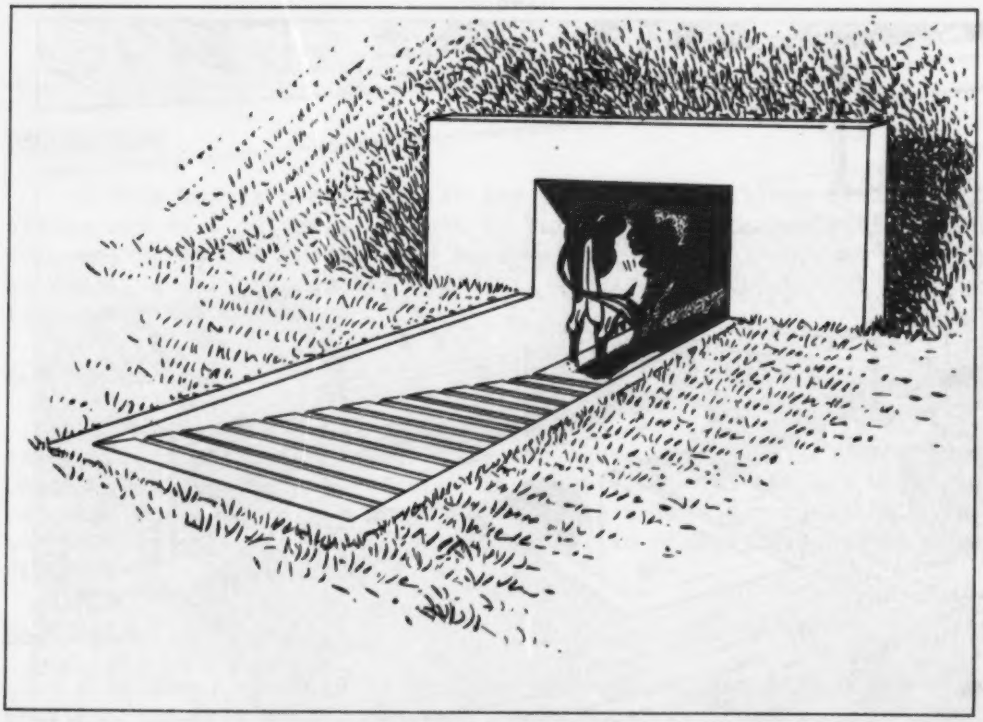


Drop box attached to existing culvert

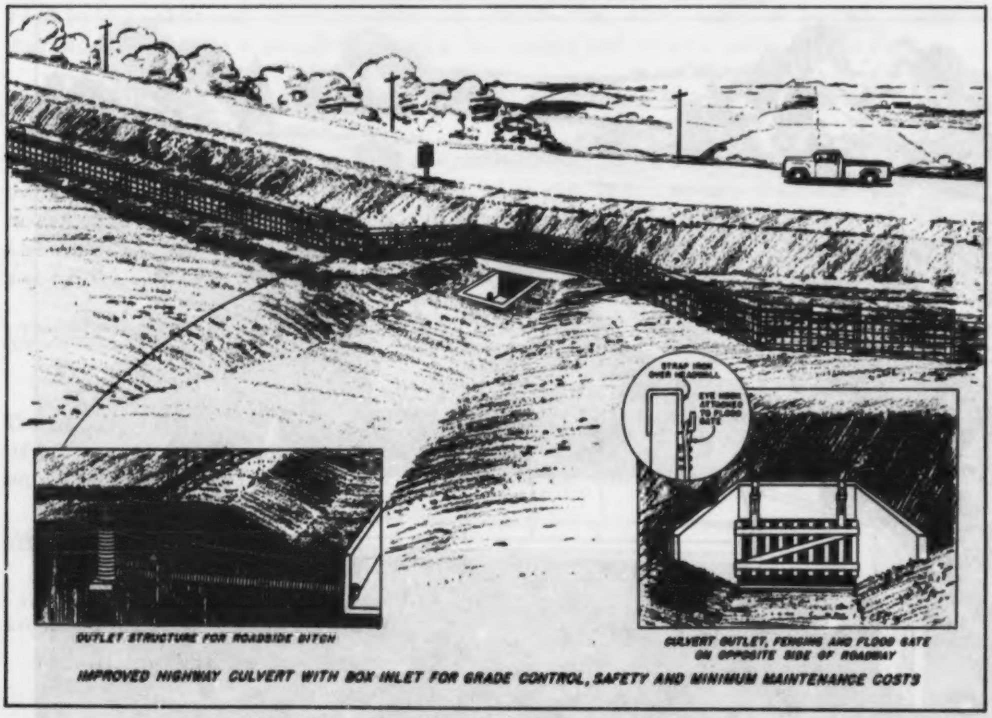


New culvert with a box inlet

Figure 6-14 Drop box (culvert inlet)



Drop box with cattle ramp



STRAP IRON OVER HEADWALL
EYE HOOK ATTACHED TO FLOOD GATE
OUTLET STRUCTURE FOR ROADSIDE DITCH
CULVERT OUTLET, FENCING AND FLOOD GATE ON OPPOSITE SIDE OF ROADWAY
IMPROVED HIGHWAY CULVERT WITH BOX INLET FOR GRADE CONTROL, SAFETY AND MINIMUM MAINTENANCE COSTS

Drop box for highway erosion control

Figure 6-15 Other uses for drop boxes

vertical curve section, steep-sloped channel, and outlet. The major part of the drop in water surface takes place in a channel. Flow passes through the inlet and down the paved channel to the floor of the outlet. (Figure 6-16)

MATERIAL

Reinforced concrete is the most widely used and safest material for large chutes.

FUNCTIONAL USES

1. To control the gradient in either natural or constructed channels.
2. To serve as a spillway for flood prevention, water conservation, and sediment-collecting structures.

ADAPTABILITY

The concrete chute is particularly adapted to high overfalls where a full flow structure is required and where site conditions do not permit the use of a detention-type structure. It also may be used with detention dams, taking advantage of the temporary storage to reduce the required capacity and the cost of the chute.

ADVANTAGES

It usually is more economical than a drop inlet structure when large capacities are required.

LIMITATIONS

There is considerable danger of undermining of the structure by rodents. In poorly drained locations, seepage may weaken the foundation. It must be placed on compacted fill or on undisturbed soil in an abutment.

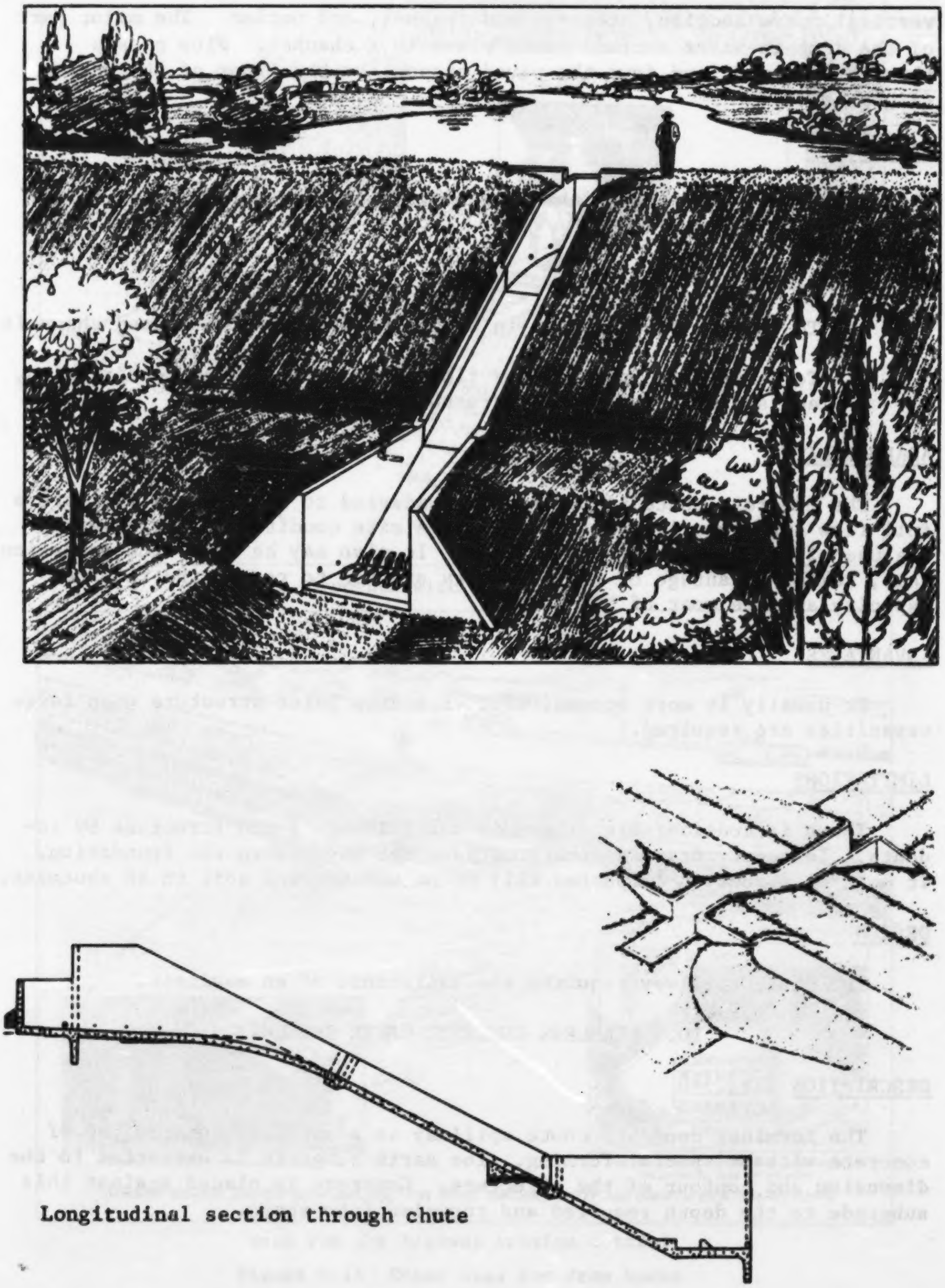
DESIGN

The chute spillway requires the assistance of an engineer.

10. FORMLESS CONCRETE CHUTE SPILLWAY

DESCRIPTION

The formless concrete chute spillway is a spillway constructed of concrete without special forming. The earth subgrade is excavated to the dimension and contour of the structure. Concrete is placed against this subgrade to the depth required and troweled into shape.



Longitudinal section through chute

Figure 6-16 Reinforced concrete chute spillway

MATERIALS

Concrete with at least a 28-day strength of 2,500 lbs. per square inch should be used. Temperature steel is required and may be either reinforcing steel or welded wire mesh.

FUNCTIONAL USE

The formless chute may be used to: control overfalls in natural and constructed waterways; prevent erosion at the ends of terraces, outlets and waterways; and to lower runoff water over drainage ditchbanks.

ADAPTABILITY

This type of structure is used for low heads and where low spillway capacities are required. It is adapted to regions that do not have extreme variations in temperature.

ADVANTAGES

The spillway is easy to construct. Inexperienced labor can be trained to install the formless chute in a relatively short time. The elimination of wall forming produces a major saving in time and costs.

LIMITATIONS

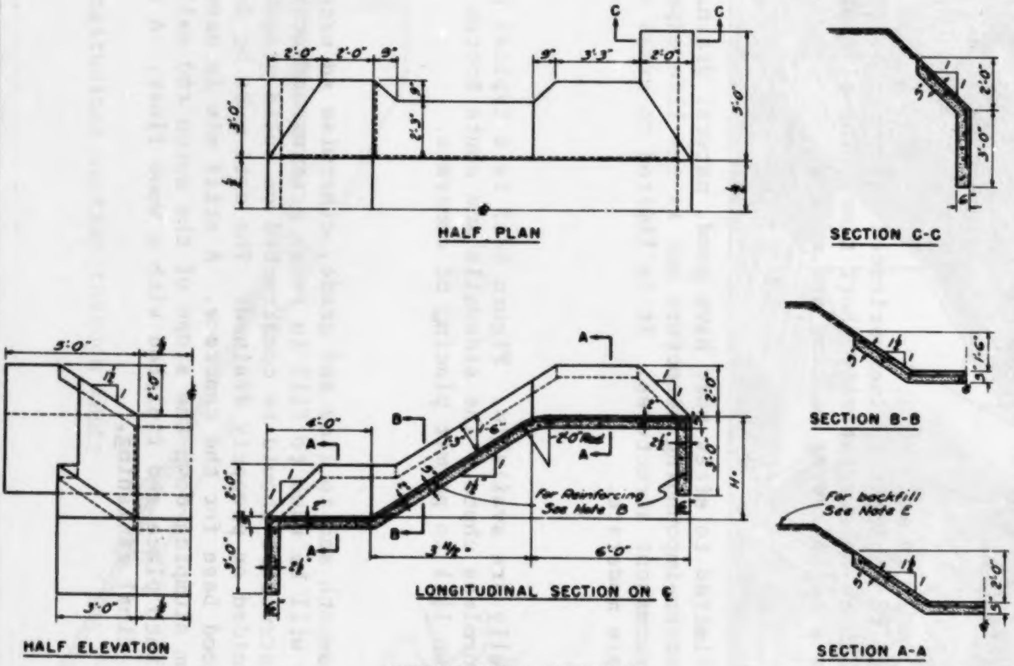
This structure is limited to sites that have good, natural drainage. It cannot be used as a water-impounding structure nor is the life expectancy as long as other permanent structures. It is limited to areas where temperature variations are moderate.

DESIGN

Standard plans usually are available. Figure 6-17 is a typical plan for a small, low-head formless chute. The sidewalls and chute bottom should be no steeper than 1½:1 to permit placing of concrete.

CONSTRUCTION

Grading should be smooth and to line and grade, otherwise an excessive amount of concrete will be used to fill in rough grading and overcutting. This type of structure should be constructed on solid ground. Seep areas should be avoided or properly drained. The soil must be damp and firm to provide a good base for the concrete. A stiff mix is needed to prevent concrete from slumping down the slope of the apron and walls. The concrete is worked into place and finished with a wood float. A steel trowel is then used for final finishing.


HALF PLAN
HALF ELEVATION
LONGITUDINAL SECTION ON ℄
SECTION C-C
SECTION B-B
SECTION A-A
For Reinforcing See Note B
For backfill See Note E
2'-0"
9"
3'-3"
5'-0"
3'-0"
4'-0"
6'-0"
2'-0" Rad.
H
A
B
C

STRUCTURAL DETAILS

NOTES:-

A. Use 5 inch thickness of concrete throughout except as dimensioned otherwise.

B. Reinforcing as indicated shall be (1) 3/8"ϕ reinforcing steel 12"c.c. both ways; or (2) No.2 gauge welded wire fabric 6"c.c. both ways. (common designation 6x6 $^{2}/_{2}$). Reinforcing bars or mesh should be lapped one foot at all joints.

C. Spillways of this type shall be constructed on solid ground. Seep areas should be avoided or properly drained with a carefully constructed toe drainage system.

D. This spillway shall not be used as a part of a water impounding structure.

E. The disturbed area adjacent to the spillway shall be backfilled, compacted and sodded.

F. The length (L) of the spillway shall be limited by the amount of concrete that can be adequately mixed, placed and finished in one day's time with the labor and equipment available or a Max. L=8'-0"

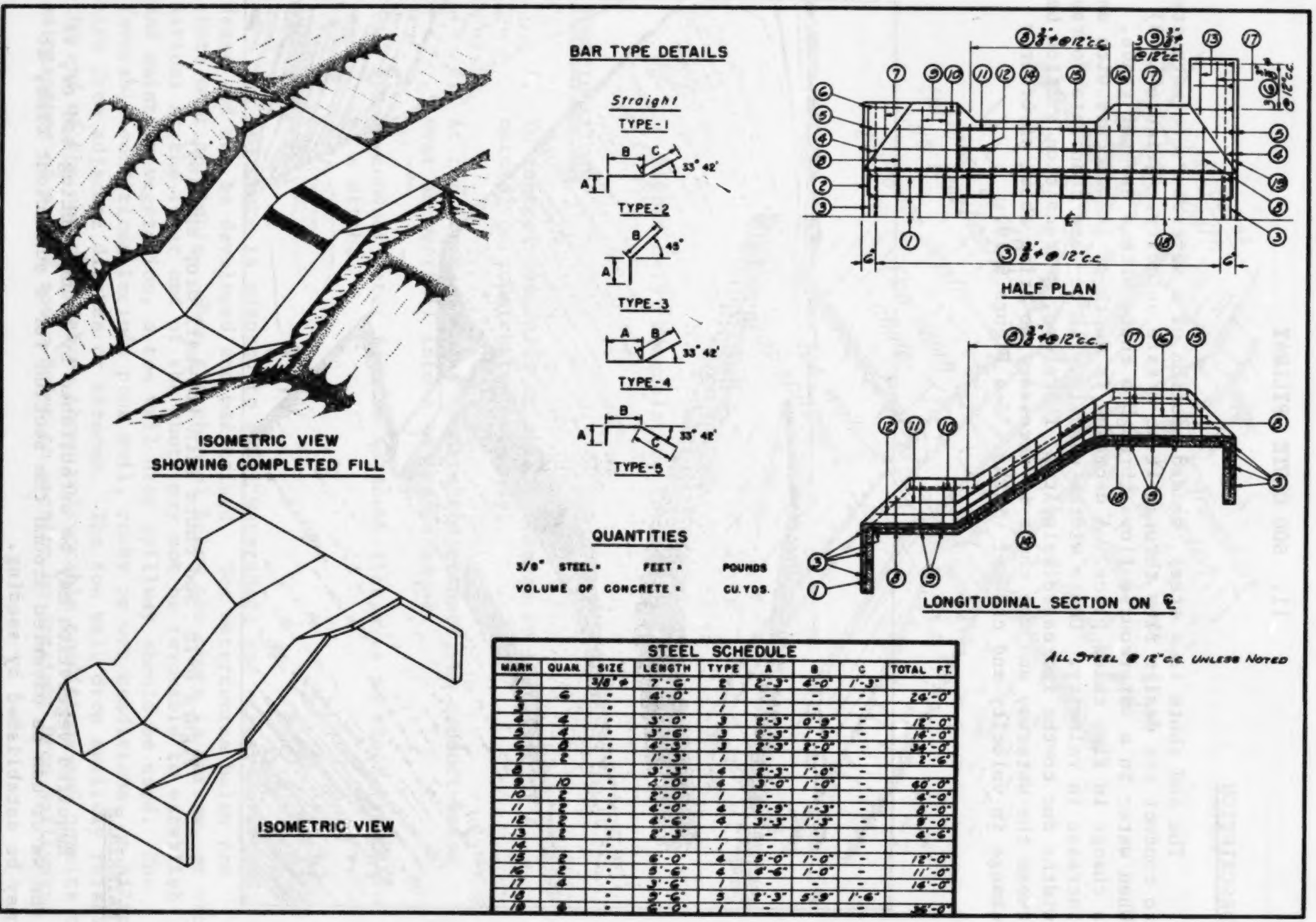
G. The maximum "H" for this spillway is 5'-0"

Discharge Capacity of Spillway in c.f.s.				
Length of Crest (L) in feet	2	4	6	8
with no freeboard	30	45	60	75
with 6" freeboard	18	28	38	48

Concrete Volumes in Cubic Yards				
Head "H" Feet	Length of Crest (L) in feet			
	2' - 0"	4' - 0"	6' - 0"	8' - 0"
4' - 0"	3.5	4.2	4.9	5.6
5' - 0"	3.7	4.4	5.2	6.0

Sheet 1 of 2

Figure 6-17 Typical standard plan for low head formless concrete chute


ISOMETRIC VIEW
SHOWING COMPLETED FILL
ISOMETRIC VIEW
BAR TYPE DETAILS
Straight
TYPE-1
TYPE-2
TYPE-3
TYPE-4
TYPE-5
A
B
C
33° 42'
45°
HALF PLAN
LONGITUDINAL SECTION ON ℄
3/8"φ @ 12" c.c.
6"
℄
All Steel @ 12" c.c. Unless Noted

QUANTITIES

3/8" STEEL = FEET = POUNDS

VOLUME OF CONCRETE = CU. YDS.

STEEL SCHEDULE

MARK	QUAN.	SIZE	LENGTH	TYPE	A	B	C	TOTAL FT.
1		3/8"φ	7'-6"	2	2'-3"	4'-0"	1'-3"	
2	6	•	4'-0"	1	-	-	-	24'-0"
3		•		1	-	-	-	
4	4	•	3'-0"	3	2'-3"	0'-9"	-	12'-0"
5	4	•	3'-6"	3	2'-3"	1'-3"	-	14'-0"
6	8	•	4'-3"	3	2'-3"	2'-0"	-	34'-0"
7	2	•	1'-3"	1	-	-	-	2'-6"
8		•	3'-3"	4	2'-3"	1'-0"	-	
9	10	•	4'-0"	4	3'-0"	1'-0"	-	40'-0"
10	2	•	2'-0"	1	-	-	-	4'-0"
11	2	•	4'-0"	4	2'-9"	1'-3"	-	8'-0"
12	2	•	4'-6"	4	3'-3"	1'-3"	-	9'-0"
13	2	•	2'-3"	1	-	-	-	4'-6"
14		•		1	-	-	-	
15	2	•	6'-0"	4	5'-0"	1'-0"	-	12'-0"
16	2	•	5'-6"	4	4'-6"	1'-0"	-	11'-0"
17	4	•	3'-6"	1	-	-	-	14'-0"
18		•	9'-6"	5	2'-3"	5'-9"	1'-6"	
19	6	•	6'-0"	1	-	-	-	36'-0"

Sheet 2 of 2

Figure 6-17 Typical standard plan for low head formless concrete chute

11. SOD CHUTE SPILLWAY

DESCRIPTION

The sod chute is a steep, sodded section of a watercourse constructed to conduct the design flow through it at a safe velocity. (Figure 6-18) When water in a watercourse flows through a chute with a steeper grade, a change in flow takes place. A decrease in depth of flow occurs with an increase in velocity. Chute widths usually will be less than watercourse widths due to the increased velocity. Therefore, a transition section between the waterway and the chute is necessary to bring about an orderly change in velocity and channel widths. See Figure 6-19.

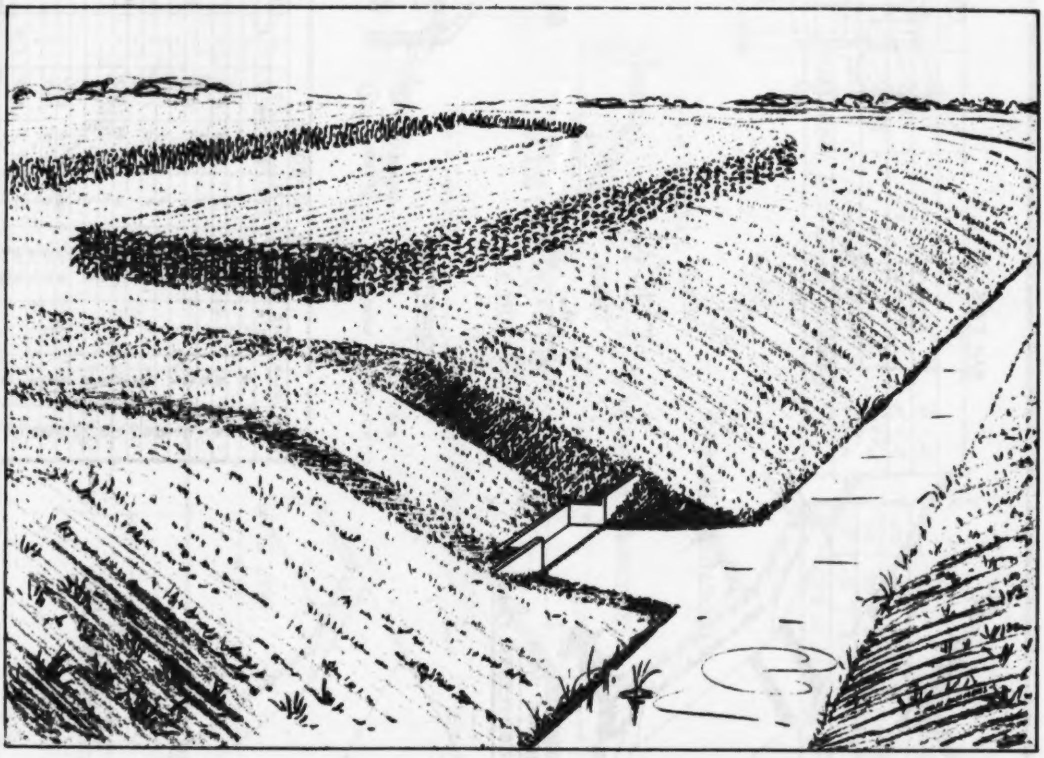


Figure 6-18 Sod chute with toe-wall drop spillway

MATERIALS

Required vegetation may be established by transplanting sod or, if the water can be diverted around the section for a sufficient time, it may be established by seeding.

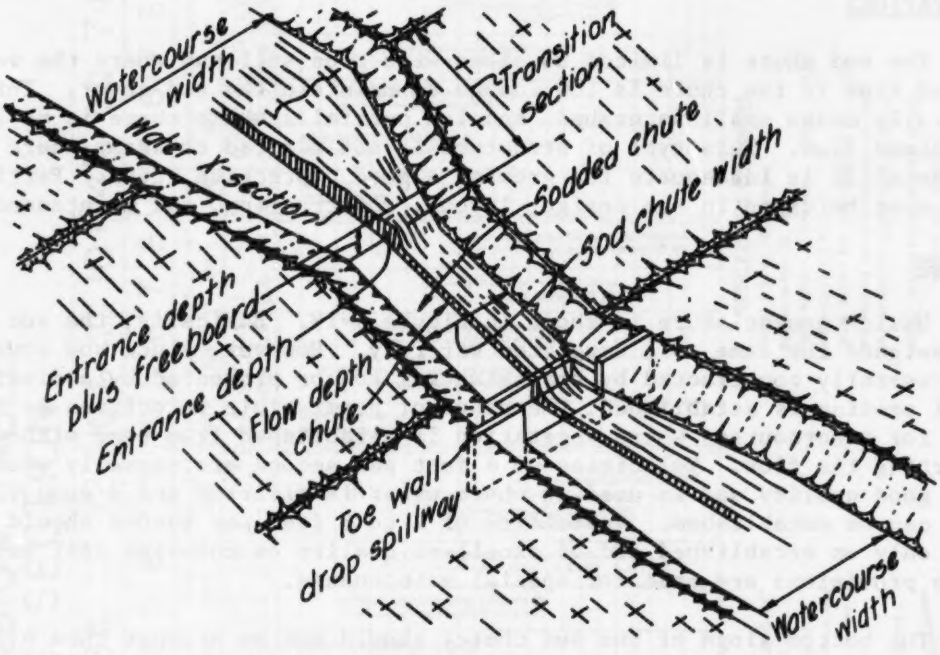

Watercourse width
Water X-section
Transition section
Sodded chute
Sod chute width
Entrance depth plus freeboard
Entrance depth
Flow depth chute
Toe wall drop spillway
Watercourse width

Figure 6-19 Nomenclature for sod chute design

FUNCTIONAL USE

1. To control overfalls or abrupt changes in the slope of a natural or constructed waterway.
2. At the lower end of a constructed channel, to conduct water over an overfall into a natural channel.
3. To conduct water from an adjacent flat area to the bottom of a ditch.

ADAPTABILITY

The sod chute is adapted to small watersheds and sites where good, dense sod can be developed and maintained. The watercourse below the chute must be stable. When the channel below the chute is narrow, or conditions at the lower end of the chute may not be favorable to establish and maintain vegetation, a toe wall drop spillway should be used. Unfavorable conditions include poor soil, rocky or wet conditions, or siltation from adjacent ditches or streams. The toe wall drop spillway raises the end of the sod chute above these unfavorable conditions and permits the maintenance of a good sod. Refer to section on Straight Drop Spillways.

ADVANTAGES

Low material costs, and may be constructed with farm labor.

LIMITATIONS

The sod chute is limited to sites with good soil and where the velocity of flow in the chute is low enough to maintain the sod cover. This generally means small watersheds and low overfalls where there is no long, sustained flow. This type of structure is not adapted to areas where normal rainfall is inadequate for growing a good protective cover. Particular care must be taken in the design, layout, construction, and maintenance.

DESIGN

Design nomenclature is shown in Figure 6-19. Basically, the sod chute is designed the same as a vegetated waterway. However, since sod chutes are generally constructed by transplanting sod or protected by a diversion until seeding is established, the range of permissible velocities is higher than for watercourses where vegetation is established from seed without diverting the flow. Velocities of 6 feet per second are normally used when good quality sod is used or where water is diverted and a good vegetation can be established. Velocities of 7 to 8 feet per second should be used only on established sod of excellent quality on cohesive soil and where provisions are made for special maintenance.

The bottom slope of the sod chutes should not be steeper than 6:1; flatter slopes are better. The chute should be designed with a flat bottom.

Chute widths usually will be less than the watercourse width, with a tendency toward restriction of flow at the entrance. To overcome this, a transition section between the waterway and the entrance to the chute should be planned so that the width of the watercourse is gradually reduced to the required width of the chute. It is also necessary to provide for a definite depth of flow at the entrance of the chute in order to assure adequate entrance capacity. Sometimes dikes are required to provide the required depth. The sod chute design chart, Figure 6-20, gives the required entrance depth for the various bottom widths and depths of flow in the chute.

When adverse conditions mentioned under "Adaptability" are encountered, a toe wall drop inlet structure should be planned. Refer to the section on Straight Drop Spillways. Note toe wall structure in Figures 6-18 and 6-19.

CONSTRUCTION

These points should be followed to assure a properly constructed sod chute:

1. Do not build on fill material.
2. Fine grade by hand if necessary to assure a uniform flat bottom from side to side and leave surface in a condition similar to a seedbed.

SOD CHUTE — DIMENSION TABLE
TRAPEZOIDAL CROSS SECTION

CHUTE SLOPE		2% SLOPE RATIO 50:1					4% SLOPE RATIO 25:1					6% SLOPE RATIO 16¼:1					8% SLOPE RATIO 12:1					10% SLOPE RATIO 10:1					14% SLOPE RATIO 7:1				
PERMISSIBLE VELOCITY, FT./SEC.		4	5	6	7	8	4	5	6	7	8	4	5	6	7	8	4	5	6	7	8	4	5	6	7	8	4	5	6	7	8
CONDITION OF SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD		FAIR SOD	GOOD SOD		EXCELLENT SOD	
ENTRANCE DEPTH FT.		0.8	1.1	1.5	1.9	2.4	0.8	1.1	1.5	1.9	2.3	0.7	1.0	1.4	1.8	2.2	0.5	0.7	1.0	1.3	1.6	0.5	0.7	0.9	1.2	1.5	0.4	0.5	0.8	1.0	1.2
CHUTE DEPTH FT.		0.6	0.8	1.0	1.2	1.4	0.5	0.7	0.9	1.1	1.3	0.4	0.6	0.8	1.0	1.2	0.3	0.4	0.5	0.7	0.9	0.2	0.3	0.4	0.6	0.7	0.2	0.3	0.3	0.4	0.5
												BOTTOM WIDTH OF CHUTE, FEET																			
REQUIRED CAPACITY Q= C.F.S.	10																10					12					15	10			
	15											10					14					18	10				24	12			
	20						10					14					19	10				24	12				32	16	10		
	25						12					18					24	12				30	15				40	20	13		
	30						15					22	10				30	15				36	19	10			49	25	16	10	
	35						18					27	12				35	18	10			42	22	12				29	19	11	
	40	10					21					31	15				40	22	12			48	26	14				34	22	13	
	45	12					25	10				36	17				45	25	14			54	30	17	10			38	25	15	
	50	14					28	12				40	20	10			50	28	16				33	19	11			42	27	17	10
	60	18					34	16				48	25	12			60	34	19	10			40	24	14	10		47	33	21	13
	70	21	10				40	20	10			57	29	15				40	23	13			47	28	17	11			39	25	16
	80	25	11				46	23	11				34	18	10			46	27	16			53	33	20	13			45	29	19
	90	29	13				53	27	13				39	21	11			53	31	18	10			37	24	15				33	22
	100	33	15				59	31	15				44	25	13			59	35	21	13			42	27	18				37	25
	120	40	19	10				38	20	10			54	31	17	10			43	26	17			51	33	22				45	31
	140	48	24	11				45	25	12				37	21	11			50	32	21				39	26					37
	160	55	28	14				52	29	16				43	26	14			59	37	25				46	30					42
	180		33	16				60	34	19	10			49	30	17				42	28				52	34					48
	200		37	19					39	22	11			56	34	20				48	32					38					
	220		41	22	10				43	25	14				38	23					36					43					
	240		45	25	12				48	29	16				42	26					40					48					
	260		50	27	14				52	32	18				47	29					43					52					
	280		54	30	16				56	35	20				51	32					47										
	300		58	33	18	10			61	38	23				55	35															

EXAMPLE

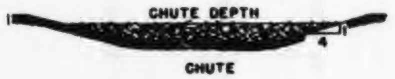
Given: Q = 90 c.f.s. Estimated runoff from watershed.

Height to control: 2.5 feet.

Try 8% slope of chute or 12:1, Chute length = 2.5 X 12 = 30 ft. (length is O.K. for site)

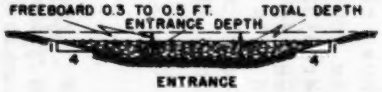
Good sod available and good soil.

Select velocity: 6 feet per second.



SOLUTION

In the left hand column under "REQUIRED CAPACITY" c.f.s. find "90" c.f.s. Follow this to right and under column "8%" slope and "6" ft. per second velocity find "31" feet bottom width. In same column on line "CHUTE DEPTH" find "0.5" foot. In same column on line "ENTRANCE DEPTH" find "1.0" foot.



CONSTRUCTION DIMENSIONS

Slope: 8% or 12:1 slope.

Bottom width: 31 feet.

Total depth: 1.0' (entrance depth) + 0.4' (freeboard) = 1.4 feet.

Chute depth: 0.5 feet. (Normal excavation and shaping will provide required depth plus additional depth for freeboard.)

NOTE: Minimum bottom width 10 feet.

BASIS OF DESIGN

$V = \frac{1.486}{n} R^{2/3} S^{1/2}$ $n = .040$

4:1 SIDE SLOPES

Figure 6-20 Sod chute design chart

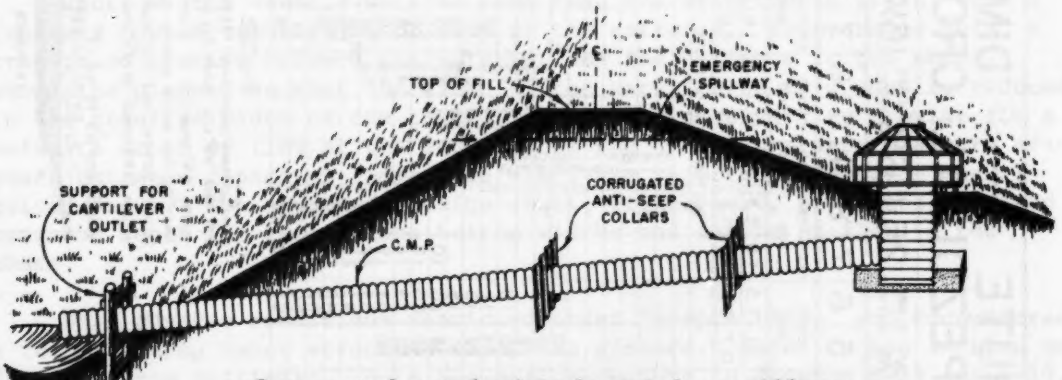
3. Cut sod thin.
   Lay sod in strips across the chute.
   Start laying sod at the bottom.
   Stagger joints of the sod strips.
   Lay sod two feet up side slopes.
   Fill any open joints with loose soil.
   Tamp or roll all laid sod.
   Sod should be pinned down in some manner. Wire (No. 9) staples, or chicken wire pegged down, are some successful methods used.

4. Protect from livestock during critical seasons.
   Mowing or controlled grazing is a necessity for maintenance.

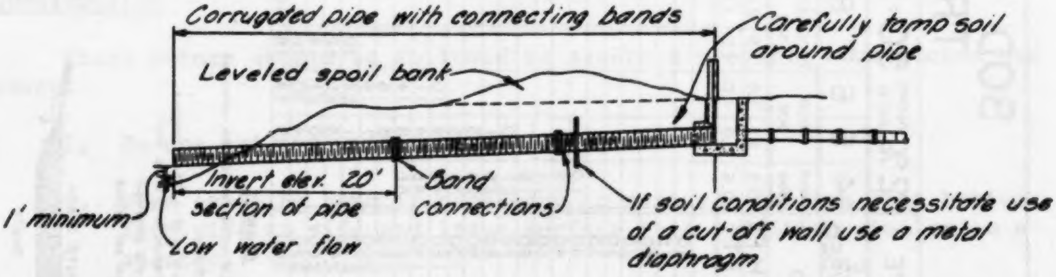
12. DROP INLET SPILLWAYS

DESCRIPTION

A drop inlet spillway is a closed conduit generally designed to carry water under pressure from above an embankment to a lower elevation. An earthen embankment is required to direct the discharge through the spillway. Thus, the usual function of a drop inlet spillway is to convey a portion of the runoff through or under an embankment without erosion. Vegetated or earth spillways around one or both ends of the embankment should always be used in conjunction with drop inlet spillways. (Figure 6-21)


TOP OF FILL
EMERGENCY SPILLWAY
SUPPORT FOR CANTILEVER OUTLET
CORRUGATED ANTI-SEEP COLLARS
C.M.P.

Corrugated metal pipe drop inlet spillway


Corrugated pipe with connecting bands
Carefully tamp soil around pipe
Leveled spoil bank
Invert elev. 20' section of pipe
Band connections
If soil conditions necessitate use of a cut-off wall use a metal diaphragm
1' minimum
Low water flow

Drop inlet spillway used to lower surface water into a channel

Figure 6-21 Examples of drop inlet spillways

MATERIALS

The riser of a drop inlet spillway may be of plain concrete, reinforced concrete, concrete blocks, or pipe. The barrel may be of reinforced concrete, concrete or clay tile, or corrugated or smooth metal pipe having watertight joints.

FUNCTIONAL USES

1. Principal spillways for farm ponds or reservoirs.
2. Grade stabilization.
3. At lower end of water disposal system.
4. Principal spillways for debris basins.
5. Roadway structures.
6. Flood prevention structures.
7. Surface water inlet for drainage or irrigation.

ADAPTABILITY

It is a very efficient structure for controlling relatively high gully heads, usually above 10 feet. It is well adapted to sites providing an appreciable amount of temporary storage above the inlet. It may also be used in connection with relatively low heads, as in the case of a drop inlet on a road culvert, or in passing surface water through a spoil bank along a drainage ditch.

ADVANTAGES

For high heads, it requires less material than a drop spillway. Where an appreciable amount of temporary storage is available, the capacity of the spillway can be materially reduced. Besides effecting a reduction in cost, this reduction of discharge results in a lower peak channel flow below, and can be a favorable factor in downstream channel grade stabilization and flood prevention.

LIMITATIONS

Small drop inlets are subject to stoppage by debris. It is limited to locations where satisfactory earth embankments can be constructed.

CLASSIFICATION

Drop inlet spillways are classified according to material into two general types: pipe drop inlets constructed of some type of pipe; and the monolithic box-type of reinforced concrete.

PIPE DROP INLET DESIGN

Pipe drop inlets usually are confined to smaller jobs where:

1. The value of the improvement may not justify the use and cost of monolithic reinforced concrete.

2. Where considerable storage is available in proportion to the size of the watershed.

3. Where the useful life of the project is limited.

Large size pipe drop inlets require the services of an engineer. The smaller sizes generally used in farm ponds can often be designed by the Work Unit staff when standard plans are available.

When corrugated or helical metal pipe is planned, only the heavier weight should be used, following the more conservative recommendations of culvert pipe manufacturers. A coating of bituminous material will extend the effective life of this type of pipe. All joints should be provided with watertight metal bands caulked or otherwise sealed against leakage, and antiseep collars used to prevent seepage along the pipe. Sheet metal antiseep collars, or diaphragms, furnished by culvert pipe manufacturers, have a watertight connection to the outside of the pipe. This type of collar is superior to concrete collars for metal pipe because distortion of the pipe from loading may crack the concrete collar or rupture the pipe; whereas a metal antiseep collar will adjust and remain intact.

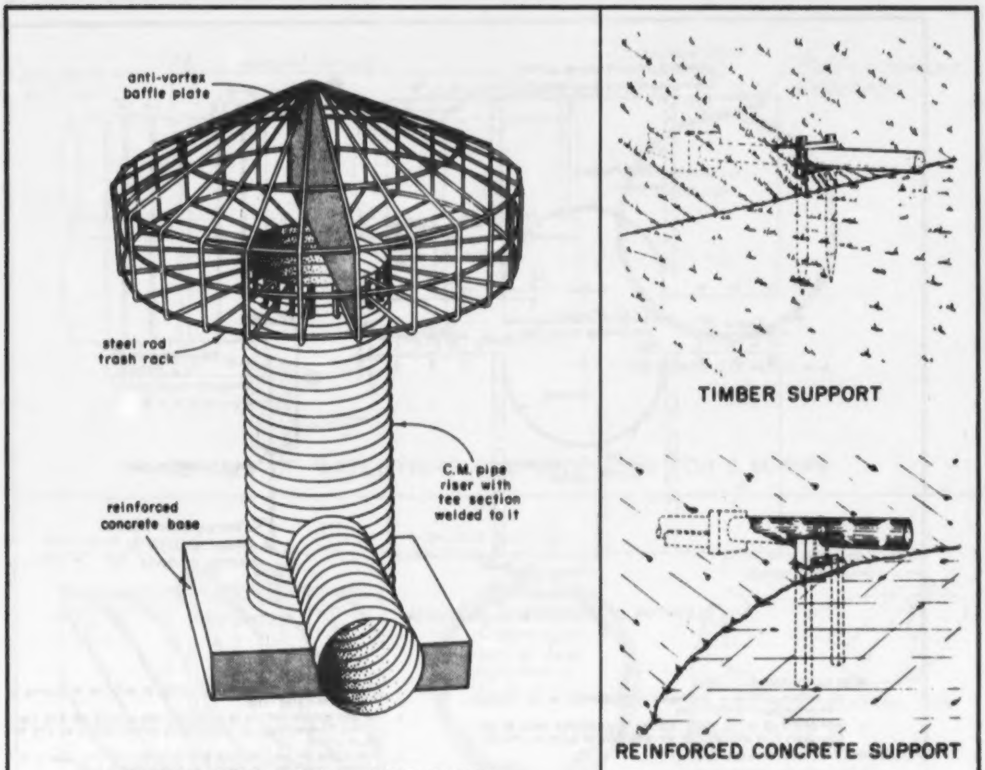
Typical appurtenances for corrugated metal (C.M.) pipe drop inlets are shown in Figure 6-22 - sheets 1, 2 and 3. When pipe drop inlets are used as spillways for storage reservoirs where the water must be released downstream, such as irrigation reservoirs, some type of release facility must be provided. Figure 6-23, sheets 1 and 2, shows typical details for release by an inclined gate structure.

Figure 6-24 can be used to determine capacity of 8- and 12-inch C.M. pipe drop inlets, as well as the height of riser required to provide the capacities shown. Pipe capacities for larger corrugated metal pipe are given in Figure 6-25 and for concrete pipe in Figure 6-26 based on required inlet conditions for pipe flow. The required inlet condition can be determined from Figure 6-27.

Reinforced concrete culvert pipe or water pipe will make a more satisfactory pipe drop inlet than corrugated metal, particularly for embankment heights greater than 20 feet, or where long service life is desired. Concrete pipe must be properly cradled and bedded. All joints must be watertight.

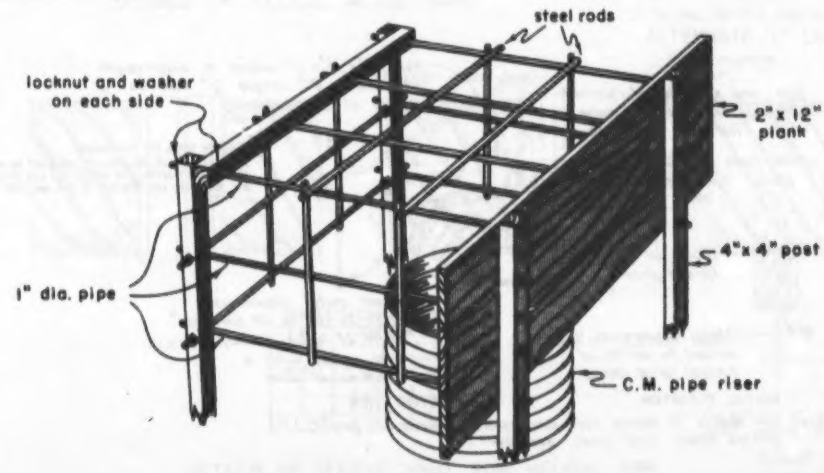
The design of a drop inlet spillway cannot be made independently of the design of the earth embankment, emergency spillway, and other elements of the total structure.

The design should provide for sufficient temporary storage between the crest of the inlet and the emergency spillway to permit a drop inlet spillway of reasonable size and cost. The size of the drop inlet spillway depends largely on the amount of this temporary storage. Tailwater will influence the layout of the spillway outlet and the amount of hydraulic head available to produce discharge through the spillway. Therefore, it must be determined accurately for each location.


anti-vortex baffle plate
steel rod trash rack
C.M. pipe riser with tee section welded to it
reinforced concrete base
TIMBER SUPPORT
REINFORCED CONCRETE SUPPORT

CORRUGATED METAL PIPE RISER WITH CONICAL TRASH RACK AND BAFFLE

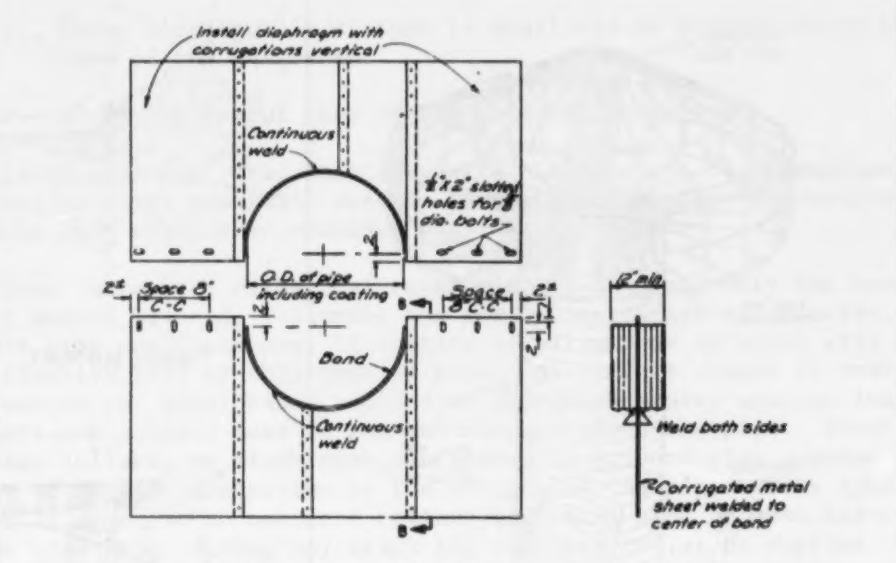
TYPE OF SUPPORT FOR CANTILEVER OUTLETS


steel rods
locknut and washer on each side
2" x 12" plank
4" x 4" post
1" dia. pipe
C.M. pipe riser

TIMBER HEADWALL AND TRASH RACK

Figure 6-22 Appurtenance for metal pipe drop inlets

(sheet 1 of 3)


Install diaphragm with corrugations vertical
Continuous weld
⅝"X2" slotted holes for ½" dia. bolts
O.D. of pipe including coating
2"±
Space 8" C-C
Space 8" C-C
2"±
B
B
½
½
Band
Continuous weld
12" min.
Weld both sides
Corrugated metal sheet welded to center of band

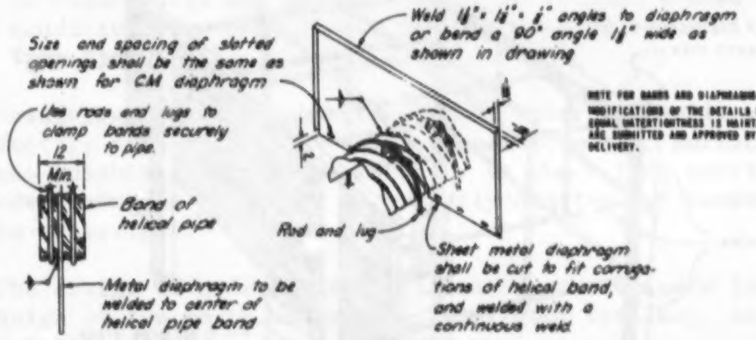
ELEVATION OF UNASSEMBLED DIAPHRAGM

SECTION B-B

NOTES FOR DIAPHRAGMS:

1. ALL MATERIALS TO BE IN ACCORDANCE WITH CONSTRUCTION AND CONSTRUCTION MATERIALS SPECIFICATIONS.
2. WHEN SPECIFIED ON THE PLANS, COATING OF DIAPHRAGMS SHALL BE IN ACCORDANCE WITH CONSTRUCTION AND CONSTRUCTION MATERIAL SPECIFICATIONS.
3. UNASSEMBLED DIAPHRAGMS SHALL BE MARKED BY PAINTING OR TAGGING TO IDENTIFY MATCHING PAIRS.
4. THE LAP BETWEEN THE TWO HALF SECTIONS AND BETWEEN THE PIPE AND CONNECTING BAND SHALL BE CAULKED WITH ASPHALT MASTIC AT TIME OF INSTALLATION.
5. EACH DIAPHRAGM SHALL BE FURNISHED WITH TWO 1/2" DIA. RODS WITH STANDARD TANK LUGS FOR CONNECTING DIAPHRAGMS TO PIPE.

DETAILS OF CORRUGATED METAL DIAPHRAGM


Weld 1½" × 1½" × ¼" angles to diaphragm or bend a 90° angle 1½" wide as shown in drawing
Size and spacing of slotted openings shall be the same as shown for CM diaphragm
Use rods and lugs to clamp bands securely to pipe.
12 Min.
Band of helical pipe
Rod and lug
Metal diaphragm to be welded to center of helical pipe band
Sheet metal diaphragm shall be cut to fit corrugations of helical band, and welded with a continuous weld
B
B

NOTE FOR BANDS AND DIAPHRAGMS:
MODIFICATIONS OF THE DETAILS SHOWN MAY BE USED PROVIDING EQUAL WATERTIGHTNESS IS MAINTAINED AND DETAILED DRAWINGS ARE SUBMITTED AND APPROVED BY THE ENGINEER PRIOR TO DELIVERY.

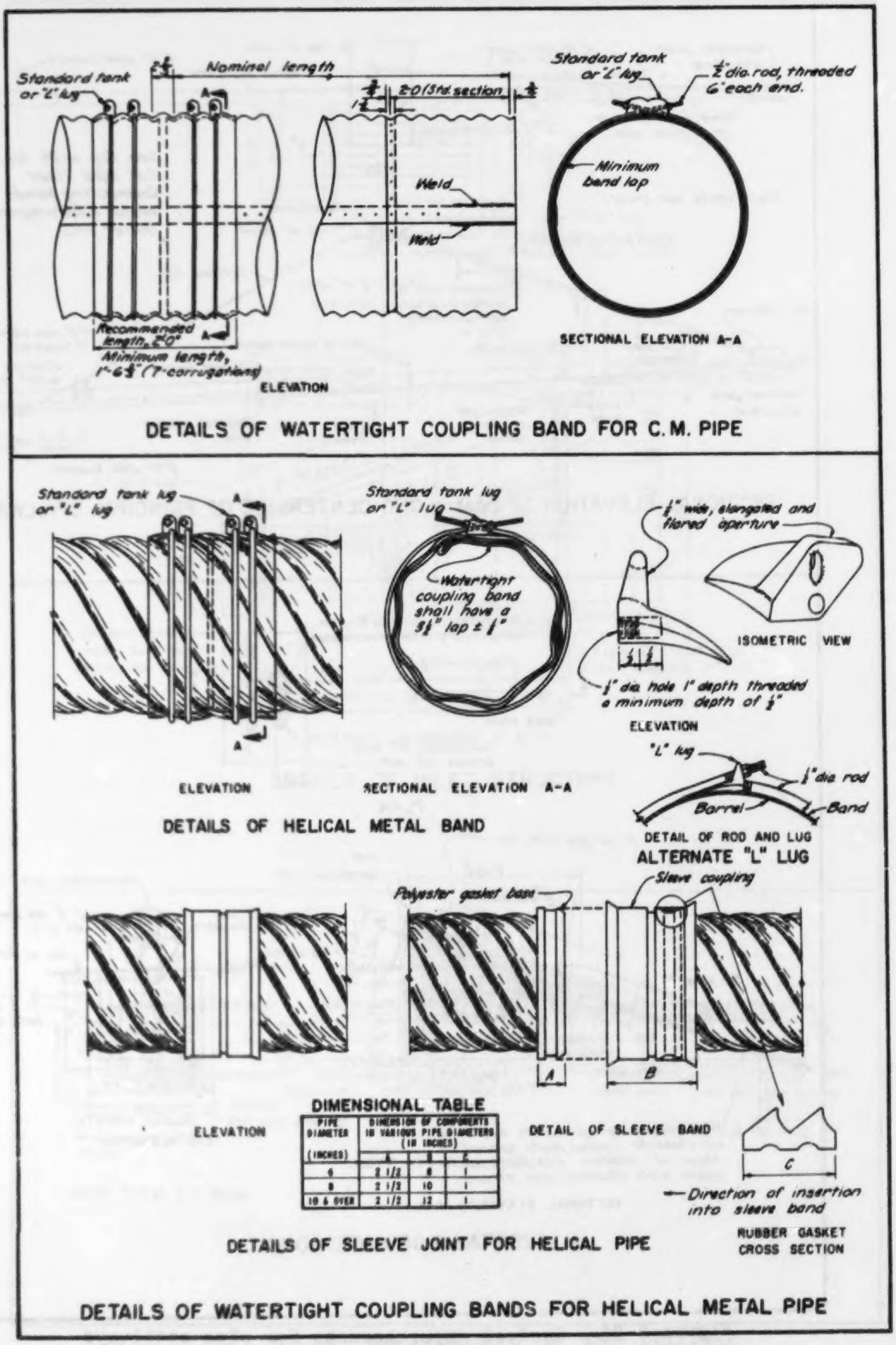
PARTIAL ELEVATION

ISOMETRIC VIEW

Note: For details of fabrication dimensions, minimum gages, slotted holes, and notes, see sheet 1

DETAILS OF HELICAL PIPE DIAPHRAGM

Figure 6-22 Appurtenances for metal pipe drop inlets (sheet 2 of 3)

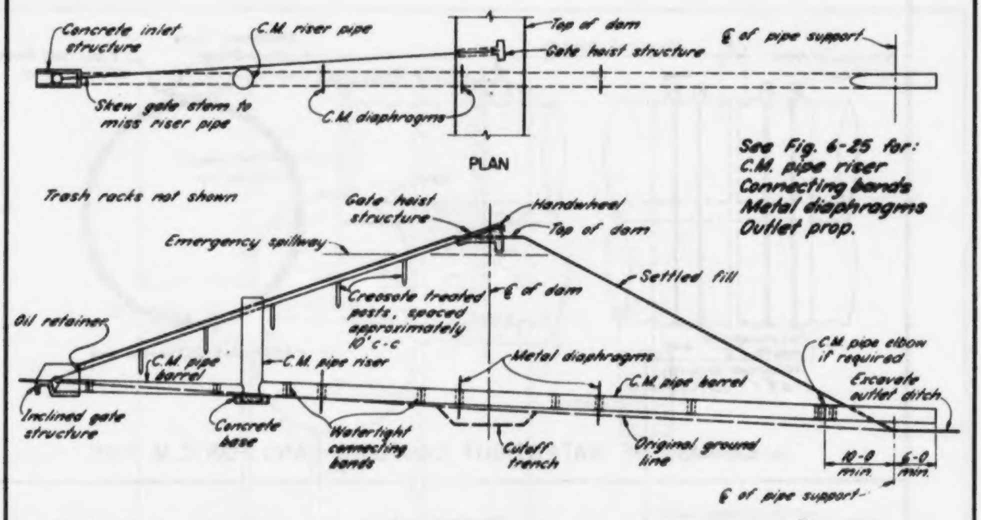

Standard tank or "L" lug
2 1/2
Nominal length
1/2
1 1/2
2'-0 (Std. section
1/2
Weld
Weld
A
A
Recommended length, 2'-0"
Minimum length, 1'-6 3/4" (7-corrugations)
ELEVATION
Standard tank or "L" lug
1/2" dia. rod, threaded 6" each end.
Minimum band lap
SECTIONAL ELEVATION A-A
DETAILS OF WATERTIGHT COUPLING BAND FOR C.M. PIPE
Standard tank lug or "L" lug
A
A
Standard tank lug or "L" lug
Watertight coupling band shall have a 3 1/2" lap ± 1/2"
1/2" wide, elongated and flared aperture
ISOMETRIC VIEW
1/2" dia hole 1" depth threaded a minimum depth of 1/2"
ELEVATION
"L" lug
1/2" dia rod
Barrel
Band
ELEVATION
SECTIONAL ELEVATION A-A
DETAILS OF HELICAL METAL BAND
DETAIL OF ROD AND LUG
ALTERNATE "L" LUG
Polyester gasket base
Sleeve coupling
A
B
C
ELEVATION
DETAIL OF SLEEVE BAND
Direction of insertion into sleeve band
RUBBER GASKET CROSS SECTION
DETAILS OF SLEEVE JOINT FOR HELICAL PIPE
DETAILS OF WATERTIGHT COUPLING BANDS FOR HELICAL METAL PIPE

DIMENSIONAL TABLE

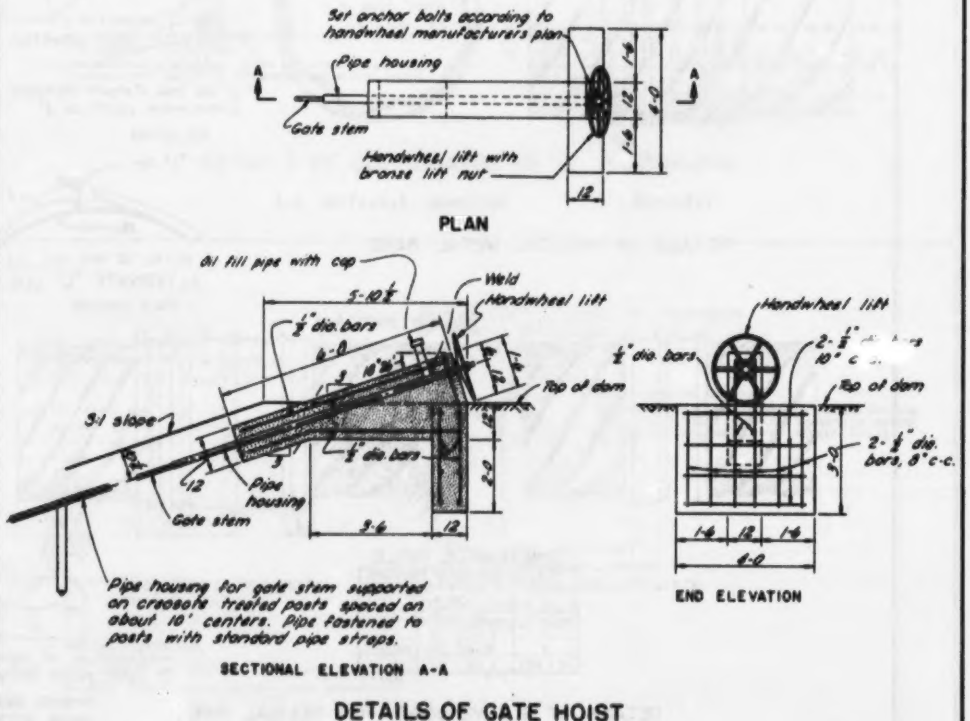
PIPE DIAMETER (INCHES)	DIMENSION OF COMPONENTS IN VARIOUS PIPE DIAMETERS (IN INCHES)		
	A	B	C
6	2 1/2	8	1
8	2 1/2	10	1
10 & OVER	2 1/2	12	1

Figure 6-22 Appurtenances for metal pipe drop inlets

(sheet 3 of 3)


Concrete inlet structure
C.M. riser pipe
Top of dam
Gate hoist structure
℄ of pipe support
Skew gate stem to miss riser pipe
C.M. diaphragms
PLAN
See Fig. 6-25 for:
C.M. pipe riser
Connecting bands
Metal diaphragms
Outlet prop.
Trash racks not shown
Gate hoist structure
Handwheel
Top of dam
Emergency spillway
Creosote treated posts, spaced approximately 10' c-c
℄ of dam
Settled fill
Oil retainer
C.M. pipe barrel
C.M. pipe riser
Metal diaphragms
C.M. pipe barrel
C.M. pipe elbow if required
Excavate outlet ditch
Inclined gate structure
Concrete base
Watertight connecting bands
Cutoff trench
Original ground line
10-0 min.
6-0 min.
℄ of pipe support

SECTIONAL ELEVATION OF DAM ALONG CENTERLINE OF PRINCIPAL SPILLWAY


Set anchor bolts according to handwheel manufacturers plan
Pipe housing
A
A
Gate stem
Handwheel lift with bronze lift nut
1-6
12
1-6
4-0
12
PLAN
Oil fill pipe with cap
Weld
Handwheel lift
5-10½
½" dia. bars
4-0
16"
3
3
1-6
12
Top of dam
3:1 slope
½" dia. bars
12
Pipe housing
Gate stem
3-6
12
2-0
Handwheel lift
½" dia. bars
2-½" dia. bars 10" c-c
Top of dam
2-½" dia. bars, 8" c-c.
3-0
1-6
12
1-6
4-0
END ELEVATION
Pipe housing for gate stem supported on creosote treated posts spaced on about 10' centers. Pipe fastened to posts with standard pipe straps.
SECTIONAL ELEVATION A-A

DETAILS OF GATE HOIST

Figure 6-23 Typical appurtenances for pipe spillways with inclined gate release structure

(sheet 1 of 2)

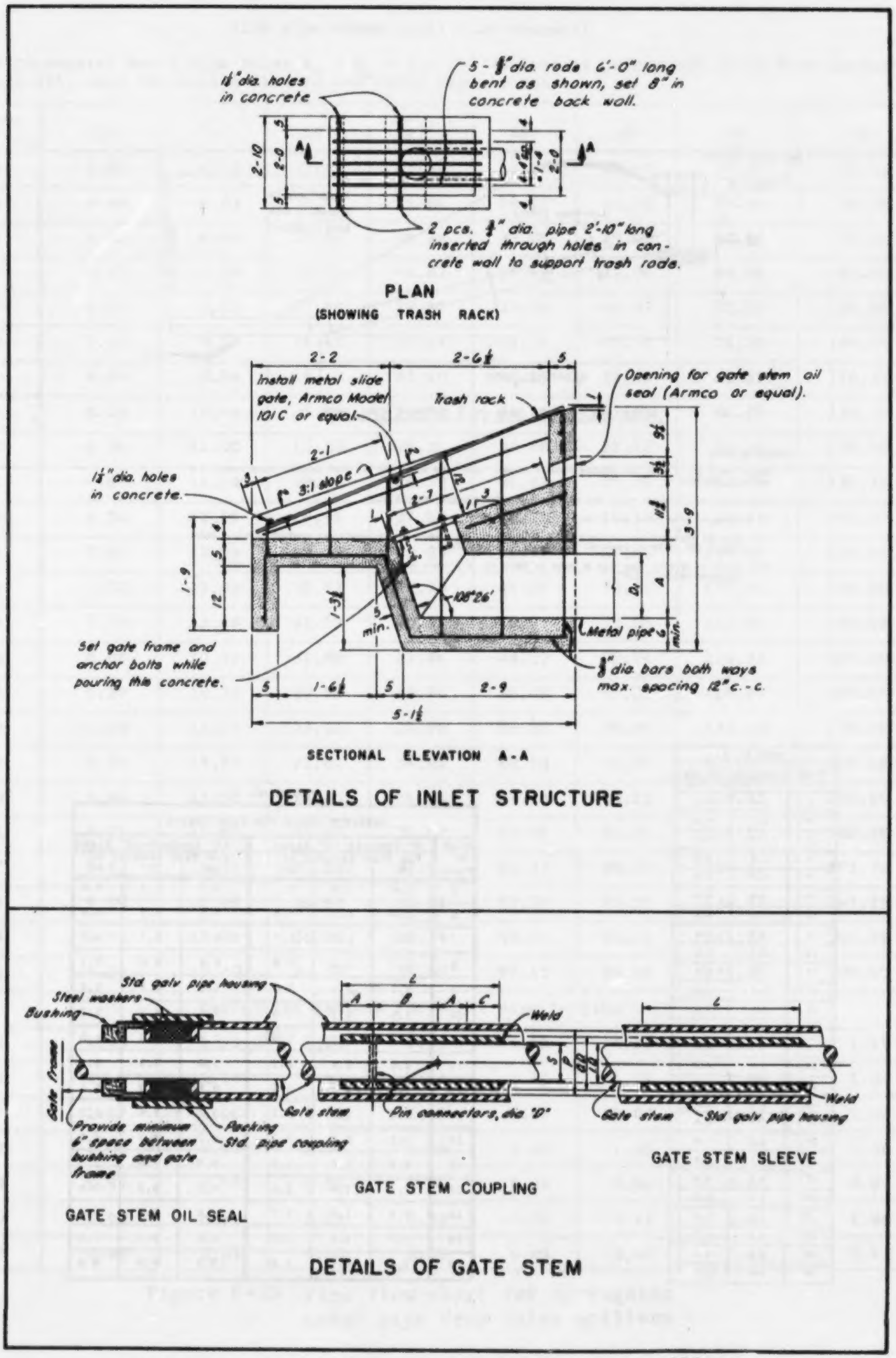
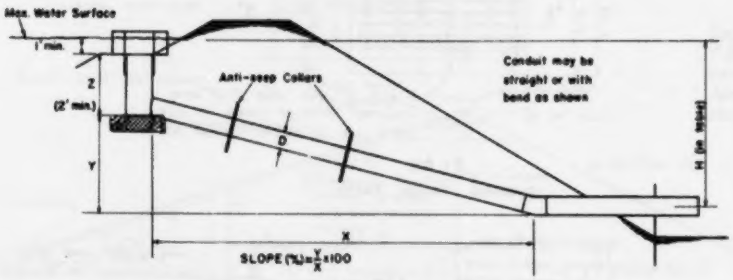

1½" dia. holes in concrete
5 - ⅝" dia. rods 6'-0" long bent as shown, set 8" in concrete back wall.
2-10
2-0
5
5
A
A
4
1-4
2-0
4
2 pcs. ¾" dia. pipe 2'-10" long inserted through holes in concrete wall to support trash rods.
PLAN
(SHOWING TRASH RACK)
2-2
2-6½
5
Install metal slide gate, Armco Model 101C or equal.
Trash rack
Opening for gate stem oil seal (Armco or equal).
2-1
3:1 slope
3
2-7
1
3
1½" dia. holes in concrete.
4
5
12
1-9
1-3½
5 min.
108°26'
D
A
3-9
Metal pipe
min.
Set gate frame and anchor bolts while pouring this concrete.
⅝" dia. bars both ways max. spacing 12" c.-c.
5
1-6½
5
2-9
5-1½
SECTIONAL ELEVATION A-A
DETAILS OF INLET STRUCTURE
Std galv pipe housing
Steel washers
Bushing
Gate frame
Provide minimum 6" space between bushing and gate frame
Packing
Std. pipe coupling
GATE STEM OIL SEAL
L
A
B
A
C
Weld
Gate stem
Pin connectors, dia "D"
S
P
GATE STEM COUPLING
L
Weld
Gate stem
Std galv pipe housing
GATE STEM SLEEVE
DETAILS OF GATE STEM

Figure 6-23 Typical appurtenances for pipe spillway with inclined gate release structure (sheet 2 of 2)
]



CROSS SECTION OF DAM ON ℄ OF PIPE SPILLWAY

Height of Riser

1. Enter Table No. 1 with the planned conduit slope. (See view above and use next largest whole number for entering table.)
2. From Table No. 1 obtain value for discharge (Q) for planned conduit size.
3. If Q obtained from Table No. 1 is:
   - (a) greater than Q shown in Table No. 2 (for the design head, conduit length and conduit size), a riser height (B) of 5D is required to provide full pipe flow.
   - (b) equal to or less than that Q shown in Table No. 2 a riser height (B) less than 5D can be used. (minimum height = 2.0').

TABLE NO. 1

Slope %	Discharge (Q) cfs 8" Pipe	 12" Pipe
5	1.4	4.1
6	1.5	4.5
7	1.7	4.9
8	1.8	5.2
9	1.9	5.5
10	2.0	5.8
11	2.1	6.1
12	2.2	6.4
13	2.3	6.6
14	2.4	6.9
15	2.4	7.1
16	2.5	7.3
17	2.6	7.6
18	2.7	7.8
19	2.7	8.0
20	2.8	8.2
21	2.9	8.4
22	2.9	8.6
23	3.0	8.8
24	3.1	9.0
25	3.1	9.2
26	3.2	9.3
27	3.3	9.5
28	3.3	9.7
29	3.4	9.9
30	3.4	10.1

TABLE NO. 2

CAPACITY TABLE FOR PIPE INLETS

Head H Feet	8" Conduit-18" Riser For Pipe Lengths of: 50'	 70'	 90'	12" Conduit-18" Riser For Pipe Lengths of: 50'	 70'	 90'
5	1.8	1.6	1.4	5.0	4.4	4.0
6	2.0	1.7	1.5	5.5	4.9	4.4
7	2.1	1.9	1.7	6.0	5.3	4.7
8	2.3	2.0	1.8	6.4	5.6	5.1
9	2.4	2.1	1.9	6.8	6.0	5.4
10	2.6	2.2	2.0	7.1	6.3	5.7
11	2.7	2.3	2.1	7.5	6.6	6.0
12	2.8	2.4	2.2	7.8	6.9	6.2
13	2.9	2.5	2.3	8.1	7.2	6.4
14	3.0	2.6	2.[illegible]	8.4	7.4	6.7
15	3.1	2.7	2.4	8.7	7.7	6.9
16	3.2	2.8	2.5	9.0	7.9	7.2
17	3.3	2.9	2.6	9.3	8.2	7.4
18	3.4	3.0	2.7	9.6	8.4	7.6
19	3.5	3.1	2.7	9.8	8.7	7.8
20	3.6	3.1	2.8	10.1	8.9	8.0

Figure 6-24 Capacity chart for 8" and 12" C.M. pipe drop inlet spillway

PIPE FLOW CHART (Full flow assumed)

For Corrugated Metal Pipe Inlet $K_e + K_b = 1.0$ and 70 feet of Corrugated Metal Pipe Conduit n = 0.025. Note correction factors for other pipe lengths.

Dia. H	12"	15"	18"	21"	24"	30"	36"	42"
2	2.84	4.92	7.73	11.30	15.60	26.60	40.77	58.12
3	3.48	6.03	9.47	13.84	19.10	32.58	49.93	71.19
4	4.02	6.96	10.94	15.98	22.06	37.62	57.66	82.20
5	4.49	7.78	12.23	17.87	24.66	42.06	64.46	91.90
6	4.92	8.52	13.40	19.57	27.01	46.07	70.60	100.65
7	5.32	9.21	14.47	21.14	29.19	49.77	76.28	108.75
8	5.68	9.84	15.47	22.60	31.19	53.19	81.53	116.23
9	6.03	10.44	16.41	23.97	33.09	56.43	86.49	123.30
10	6.36	11.00	17.30	25.26	34.88	59.48	91.16	129.96
11	6.67	11.54	18.14	26.50	36.59	62.39	95.63	136.33
12	6.96	12.05	18.95	27.68	38.21	65.16	99.87	142.37
13	7.25	12.55	19.72	28.81	39.77	67.83	103.96	148.21
14	7.52	13.02	20.47	29.90	41.27	70.39	107.88	153.80
15	7.78	13.48	21.19	30.95	42.72	72.85	111.66	159.18
16	8.04	13.92	21.88	31.96	44.12	75.24	115.32	164.40
17	8.29	14.35	22.55	32.94	45.48	77.55	118.87	169.46
18	8.53	14.77	23.21	33.90	46.80	79.81	122.33	174.39
19	8.76	15.17	23.84	34.83	48.08	81.99	125.67	179.15
20	8.99	15.56	24.46	35.73	49.33	84.12	128.93	183.80
21	9.21	15.95	25.07	36.62	50.55	86.21	132.13	188.36
22	9.43	16.32	25.65	37.47	51.73	88.22	135.21	192.76
23	9.64	16.69	26.23	38.32	52.90	90.21	138.27	197.12
24	9.85	17.05	26.80	39.14	54.04	92.15	141.24	201.35
25	10.05	17.40	27.35	39.95	55.15	94.05	144.15	205.50
L	Correction Factors For Other Pipe Lengths							
40	1.23	1.22	1.20	1.19	1.16	1.14	1.13	1.11
50	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
60	1.07	1.06	1.06	1.05	1.05	1.04	1.04	1.03
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
90	0.90	0.91	0.91	0.92	0.92	0.93	0.94	0.94
100	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.92

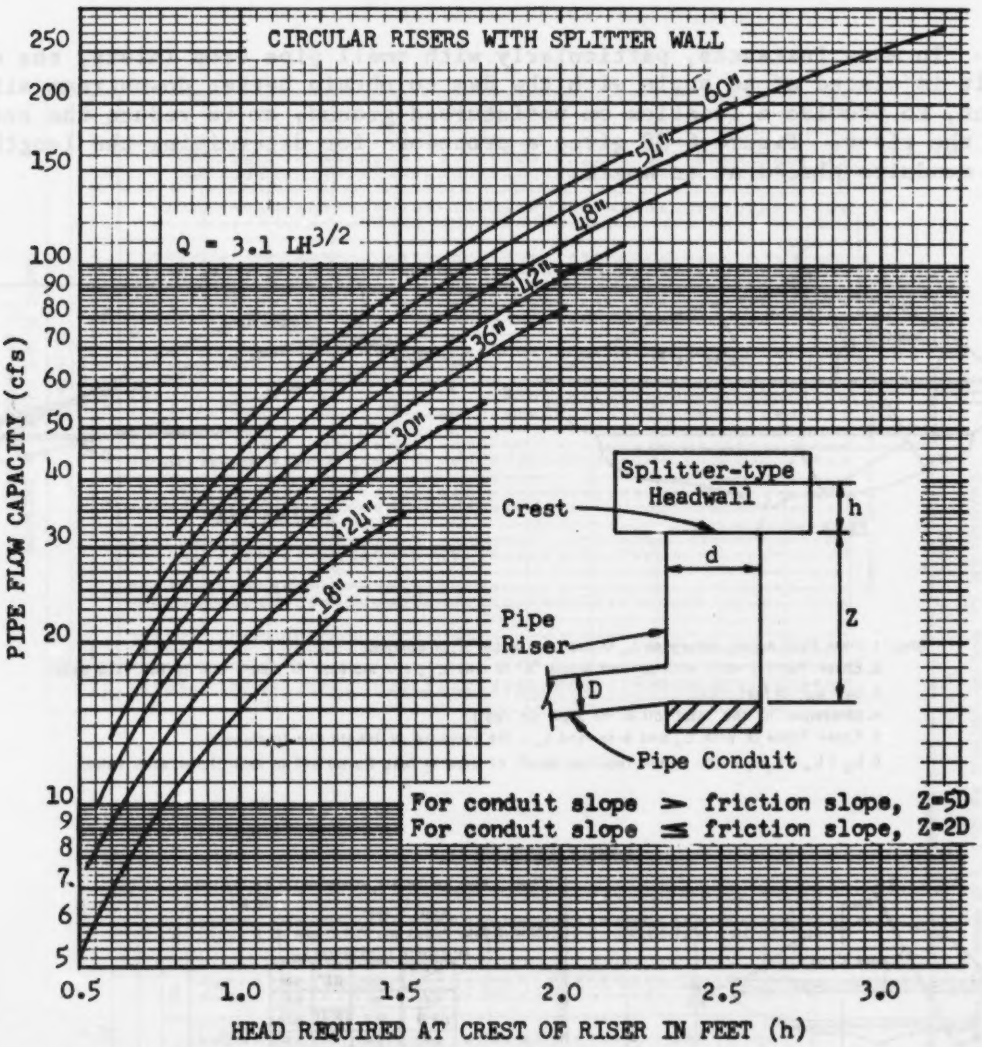
Figure 6-25 Pipe flow chart for corrugated metal pipe drop inlet spillway

PIPE FLOW CHART (Full Pipe flow assumed)

For R/C Drop Inlet, $K_e + K_b = 0.65$ with 70 feet of R/C conduit, $n = .013$. Note correction factors for other pipe lengths.

Dia. H	12"	15"	18"	21"	24"	30"	36"	42"
2	4.54	8.01	11.74	16.60	22.44	36.74	54.65	76.02
3	5.56	9.81	14.39	20.33	27.49	45.00	66.94	93.11
4	6.42	11.33	16.61	23.48	31.74	51.96	77.30	107.52
5	7.18	12.66	18.57	26.25	35.49	58.09	86.42	120.21
6	7.87	13.86	20.34	28.75	38.87	63.63	94.65	131.66
7	8.50	14.98	21.98	31.06	41.99	68.74	102.27	142.25
8	9.08	16.01	23.49	33.20	44.88	73.47	109.30	152.03
9	9.64	17.00	24.92	35.22	47.61	77.94	115.95	161.28
10	10.16	17.91	26.26	37.12	50.18	82.15	122.21	169.99
11	10.65	18.78	27.55	38.94	52.64	86.18	128.20	178.32
12	11.13	19.62	28.77	40.67	54.97	89.99	133.88	186.22
13	11.58	20.42	29.95	42.33	57.23	93.68	139.37	193.86
14	12.01	21.18	31.07	43.93	59.37	97.19	144.59	201.12
15	12.44	21.93	32.17	45.47	61.46	100.62	149.69	208.21
16	12.85	22.65	33.22	46.96	63.48	103.92	154.60	215.04
17	13.24	23.35	34.24	48.40	65.43	107.12	159.35	221.65
18	13.63	24.03	35.24	49.81	67.34	110.23	163.99	228.10
19	14.00	24.68	36.21	51.17	69.18	113.25	168.48	234.34
20	14.36	25.32	37.14	52.50	70.97	116.18	172.84	240.41
21	14.72	25.95	38.07	53.80	72.73	119.07	177.13	246.38
22	15.06	26.56	38.96	55.06	74.43	121.85	181.27	252.13
23	15.40	27.16	39.84	56.31	76.11	124.60	185.36	257.83
24	15.73	27.74	40.69	57.51	77.75	127.28	189.35	263.37
25	16.06	28.32	41.53	58.70	79.35	129.90	193.25	268.80
L	Correction Factors For Other Pipe Lengths							
40	1.15	1.13	1.11	1.09	1.08	1.06	1.06	1.05
50	1.09	1.08	1.07	1.06	1.05	1.04	1.04	1.03
60	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.96	0.96	0.97	0.97	0.98	0.98	0.98	0.99
90	0.93	0.94	0.94	0.95	0.95	0.96	0.97	0.97
100	0.90	0.91	0.92	0.93	0.93	0.95	0.95	0.96

Figure 6-26 Pipe flow chart for concrete pipe drop inlet spillway



For conduit slope > friction slope, Z=5D
For conduit slope ≤ friction slope, Z=2D

Pipe Drop Inlet Spillway Design:

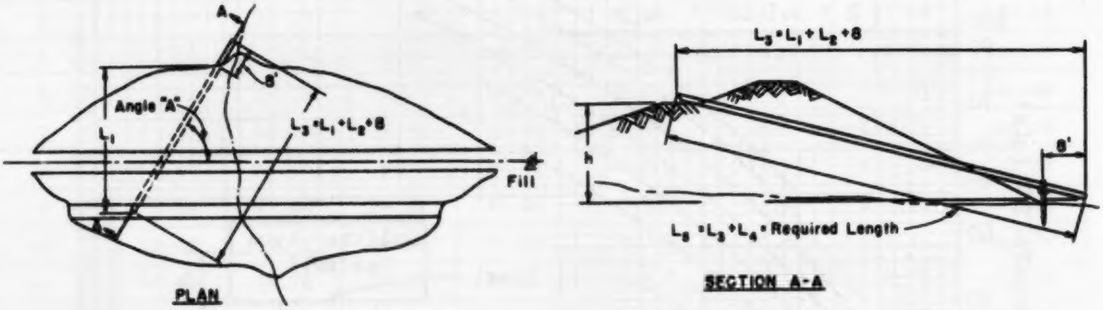
Inlet Proportions	
Pipe Conduit (D)-in.	Pipe Riser (d)-in.
8-12	18
15	21
18	24
21	30
24	30
30	36
36	48
42	54
48	60

For a given Q and H, refer to Figure 6-25 or 6-26 for conduit size. Then determine the riser diameter (d) from the Inlet Proportions table on this figure. Next, refer to the above curves, using the conduit capacity and riser diameter and find the head (h) required above the crest of the riser. The height of the riser should not be less than 5D - h, except as noted in the above sketch.

Example - Given: CMP; Q = 20 cfs; H = 14 ft., h max. 1.0 ft.; L = 70 ft. From Figure 6-25 find conduit size (D) = 18 inches. From Inlet Proportions table, riser size = 30 inches. Head (h) required for Q = 20 and d = 30 is 0.85 foot.

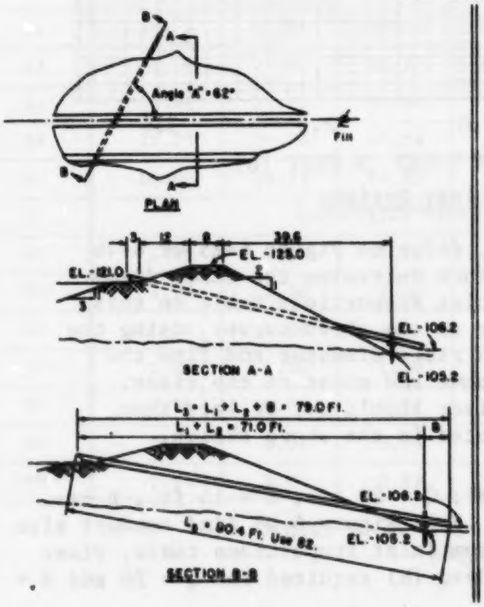
Figure 6-27 Chart for determining inlet proportions and required head over inlet

In many instances, particularly with small pipe drop inlets, the conduit is placed at an angle with the dam to obtain better downstream alignment, to provide a location on undisturbed ground, or to reduce the height of the riser. Figure 6-28 gives a procedure for determining the length of conduits placed at an angle.


A
8'
Angle "A"
L_1
$L_3 = L_1 + L_2 + 8$
℄ Fill
A
PLAN
$L_3 = L_1 + L_2 + 8$
h
8'
$L_5 = L_3 + L_4 =$ Required Length
SECTION A-A

Step 1. From field survey determine L_1 in feet and Angle "A" in degrees.
2. Enter Table I with with L_1 and Angle "A" to find L_2, the increase in length due to the skew angle.
3. $L_1 + L_2 + 8$ feet $= L_3$
4. Determine "h", the total fall in the pipe (in feet).
5. Enter Table II with L_3 and h to find L_4, the increase in length due to slope.
6. $L_3 + L_4 = L_5$, which is the required length of pipe in feet. Round off to next higher even value.

SAMPLE PROBLEM


B
A
Angle "A" = 62°
℄ Fill
B
A
PLAN
3
12
8
39.6
EL. = 125.0
EL. = 121.0
2
1
1
3
EL. = 106.2
EL. = 105.2
SECTION A-A
$L_3 = L_1 + L_2 + 8 = 79.0$ Ft.
$L_1 + L_2 = 71.0$ Ft.
8
EL. = 106.2
$L_5 = 80.4$ Ft. Use 82.
EL. = 105.2
SECTION B-B

Step 1. From Section A-A, determine $L_1 = 3 + 12 + 8 + 39.6$
$= 62.6$ Ft.
Angle "A" = 62°

Step 2. Enter Table I with 62.6 Ft. and 62°
Interpolate to determine L_2

L_1 \ ∠A	60°	62°	65°
62'	9.6		6.4
62.6	9.7	8.4	6.5
64'	9.9		6.6

$L_2 = 8.4$ Ft. = Increase in length due to the skew angle.

Step 3. Add $L_1 + L_2 + 8' = L_3$
$L_3 = 62.6 + 8.4 + 8 = 79.0$ Ft.

Step 4. Total fall in pipe: $h = 121.0 - 106.2 = 14.8$ Ft.

Step 5. Enter Table II with $h = 14.8$ and $L_3 = 79.0$
Interpolate to determine L_4:

L_3 \ h	14	14.8	16
78	1.2		1.6
79	1.2	1.4	1.6
80	1.2		1.6

$L_4 = 1.4$ Ft. = Increase in length due to slope.

Step 6. Add $L_3 + L_4 = L_5$
$L_5 = 79.0 + 1.4 = 80.4$
Round off to next higher even Ft. Final length = 82 feet

Figure 6-28 Procedure for determining length of conduit

(sheet 1 of 2)

TABLE I: VALUES OF L_2
(INCREASE IN LENGTH DUE TO SKEW)

L_1 Feet	Value of L_2 - Feet								
	Angle "A" - Degrees								
	45	50	55	60	65	70	75	80	85
40	16.6	12.2	8.8	6.2	4.1	2.6	1.4	0.6	0.2
42	17.4	12.8	9.3	6.5	4.3	2.7	1.5	0.6	0.2
44	18.2	13.4	9.7	6.8	4.5	2.8	1.6	0.7	0.2
46	19.1	14.0	10.2	7.1	4.8	3.0	1.6	0.7	0.2
48	19.9	14.7	10.6	7.4	5.0	3.1	1.7	0.7	0.2
50	20.7	15.3	11.0	7.7	5.2	3.2	1.8	0.8	0.2
52	21.5	15.9	11.5	8.0	5.4	3.3	1.8	0.8	0.2
54	22.4	16.5	11.9	8.4	5.6	3.5	1.9	0.8	0.2
56	23.2	17.1	12.4	8.7	5.8	3.6	2.0	0.9	0.2
58	24.0	17.7	12.8	9.0	6.0	3.7	2.0	0.9	0.2
60	24.9	18.3	13.2	9.3	6.2	3.9	2.1	0.9	0.2
62	25.7	18.9	13.7	9.6	6.4	4.0	2.2	1.0	0.2
64	26.5	19.5	14.1	9.9	6.6	4.1	2.3	1.0	0.2
66	27.3	20.2	14.6	10.2	6.8	4.2	2.3	1.0	0.3
68	28.2	20.8	15.0	10.5	7.0	4.4	2.4	1.0	0.3
70	29.0	21.4	15.5	10.8	7.2	4.5	2.5	1.1	0.3
72	29.8	22.0	15.9	11.1	7.4	4.6	2.5	1.1	0.3
74	30.7	22.6	16.3	11.4	7.7	4.8	2.6	1.1	0.3
76	31.5	23.2	16.8	11.8	7.9	4.9	2.7	1.2	0.3
78	32.3	23.8	17.2	12.1	8.1	5.0	2.8	1.2	0.3
80	33.1	24.4	17.7	12.4	8.3	5.1	2.8	1.2	0.3
82	34.0	25.0	18.1	12.7	8.5	5.3	2.9	1.3	0.3
84	34.8	25.7	18.5	13.0	8.7	5.4	3.0	1.3	0.3
86	35.6	26.3	19.0	13.3	8.9	5.5	3.0	1.3	0.3
88	36.4	26.9	19.4	13.6	9.1	5.6	3.1	1.4	0.3
90	37.3	27.5	19.9	13.9	9.3	5.8	3.2	1.4	0.3
92	38.1	28.1	20.3	14.2	9.5	5.9	3.2	1.4	0.3
94	38.9	28.7	20.8	14.5	9.7	6.0	3.3	1.4	0.4
96	39.8	29.3	21.2	14.9	9.9	6.2	3.4	1.5	0.4
98	40.6	29.9	21.6	15.2	10.1	6.3	3.5	1.5	0.4
100	41.4	30.5	22.1	15.5	10.3	6.4	3.5	1.5	0.4
102	42.2	31.2	22.5	15.8	10.5	6.5	3.6	1.6	0.4
104	43.1	31.8	23.0	16.1	10.8	6.7	3.7	1.6	0.4
106	43.9	32.4	23.4	16.4	11.0	6.8	3.7	1.6	0.4
108	44.7	33.0	23.8	16.7	11.2	6.9	3.8	1.7	0.4
110	45.6	33.6	24.3	17.0	11.4	7.1	3.9	1.7	0.4
112	46.4	34.2	24.7	17.3	11.6	7.2	4.0	1.7	0.4
114	47.2	34.8	25.2	17.6	11.8	7.3	4.0	1.8	0.4
116	48.0	35.4	25.6	17.9	12.0	7.4	4.1	1.8	0.4
118	48.9	36.0	26.1	18.3	12.2	7.6	4.2	1.8	0.4
120	49.7	36.6	26.5	18.6	12.4	7.7	4.2	1.8	0.5
122	50.5	37.3	26.9	18.9	12.6	7.8	4.3	1.9	0.5
124	51.4	37.9	27.4	19.2	12.8	7.0	4.4	1.9	0.5

Computed from the relationship $L_2 = L_1 \left[(\csc A) - 1\right]$

TABLE II: VALUES OF L_4
(INCREASE IN LENGTH DUE TO SLOPE)

L_3 Feet	Values of L_4											
	h - Feet											
	4	6	8	10	12	14	16	18	20	22	24	26
40	0.2	0.5	0.8	1.2	1.8	2.4	3.1	3.9	4.7			
42	0.2	0.4	0.8	1.2	1.7	2.3	2.9	3.7	4.5			
44	0.2	0.4	0.7	1.1	1.6	2.2	2.8	3.5	4.3	5.2		
46	0.2	0.4	0.7	1.1	1.5	2.1	2.7	3.4	4.2	5.0		
48	0.2	0.4	0.7	1.0	1.5	2.0	2.6	3.3	4.0	4.8	5.7	
50	0.2	0.4	0.6	1.0	1.4	1.9	2.5	3.1	3.9	4.6	5.5	
52	0.2	0.3	0.6	1.0	1.4	1.9	2.4	3.0	3.7	4.5	5.3	6.1
54	0.1	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.6	4.3	5.1	5.9
56	0.1	0.3	0.6	0.9	1.3	1.7	2.2	2.8	3.5	4.2	4.9	5.7
58	0.1	0.3	0.5	0.9	1.2	1.7	2.2	2.7	3.4	4.0	4.8	5.6
60	0.1	0.3	0.5	0.8	1.2	1.6	2.1	2.6	3.2	3.9	4.6	5.4
62	0.1	0.3	0.5	0.8	1.2	1.6	2.0	2.6	3.1	3.8	4.5	5.2
64	0.1	0.3	0.5	0.8	1.1	1.5	2.0	2.5	3.1	3.7	4.4	5.1
66	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.4	3.0	3.6	4.2	4.9
68	0.1	0.3	0.5	0.7	1.1	1.4	1.9	2.3	2.9	3.5	4.1	4.8
70	0.1	0.3	0.5	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.7
72	0.1	0.2	0.4	0.7	1.0	1.3	1.8	2.2	2.7	3.3	3.9	4.6
74	0.1	0.2	0.4	0.7	1.0	1.3	1.7	2.2	2.7	3.2	3.8	4.4
76	0.1	0.2	0.4	0.7	0.9	1.3	1.7	2.1	2.6	3.1	3.7	4.3
78	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.1	2.5	3.0	3.6	4.2
80	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.0	2.5	3.0	3.5	4.1
82	0.1	0.2	0.4	0.6	0.9	1.2	1.5	2.0	2.4	2.9	3.4	4.0
84	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.3	2.8	3.4	3.9
86	0.1	0.2	0.4	0.6	0.8	1.1	1.5	1.9	2.3	2.8	3.3	3.8
88	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.2	2.7	3.2	3.8
90	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.2	2.6	3.1	3.7
92	0.1	0.2	0.3	0.5	0.8	1.1	1.4	1.7	2.1	2.6	3.1	3.6
94	0.1	0.2	0.3	0.5	0.8	1.0	1.4	1.7	2.1	2.5	3.0	3.5
96	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5
98	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.6	2.0	2.4	2.9	3.4
100	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.6	2.0	2.4	2.8	3.3
102	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.6	1.9	2.3	2.8	3.3
104	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.5	1.9	2.3	2.7	3.2
106	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.5	1.9	2.3	2.7	3.1
108	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.6	3.1
110	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.6	3.0
112	0.1	0.2	0.3	0.4	0.6	0.9	1.1	1.4	1.8	2.1	2.5	3.0
114	0.1	0.2	0.3	0.4	0.6	0.9	1.1	1.4	1.7	2.1	2.5	2.9
116	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.4	1.7	2.1	2.5	2.9
118	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.4	1.7	2.0	2.4	2.8
120	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.7	2.0	2.4	2.8
122	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.3	1.6	1.9	2.3	2.7
124	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.3	1.6	1.9	2.3	2.7
126	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.3	1.6	1.9	2.3	2.7
128	0.1	0.1	0.2	0.4	0.6	0.8	1.0	1.3	1.6	1.8	2.2	2.6
130	0.1	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.2	2.6
132	0.1	0.1	0.2	0.4	0.5	0.7	1.0	1.2	1.5	1.8	2.2	2.5
134	0.1	0.1	0.2	0.4	0.5	0.7	1.0	1.2	1.5	1.8	2.1	2.5
136	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.5	1.8	2.1	2.5
138	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.4	1.7	2.1	2.4
140	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.2	1.4	1.7	2.0	2.4
142	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.4
144	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	2.3
146	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.6	2.0	2.3
148	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.3
150	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2

Computed from the relationship $L_4 = \sqrt{L_3^2 + h^2 - L_3}$

1. In most cases the values in the tables are so nearly the same that interpolation is not necessary. This must be decided according to the degree of accuracy required.
2. When these tables are used with drop inlet spillways, the values of h is not the total fall, but only the fall occurring within the pipe.

Figure 6-28 Procedure for determining length of conduit
(sheet 2 of 2)

The outlet of the drop inlet spillway should be in line with the downstream channel. The layout providing the shortest conduit will exist when the conduit is straight and at a 90-degree angle with the centerline of the embankment.

MONOLITHIC BOX-TYPE DROP INLET DESIGN

This type must be designed by an engineer. Reinforced concrete has been used most extensively for locations requiring a 3' x 3' culvert or larger. Removal of forms is difficult on smaller culverts. The reinforced concrete monolithic drop inlet is generally recommended for the larger and more important spillways. See Figure 6-29.

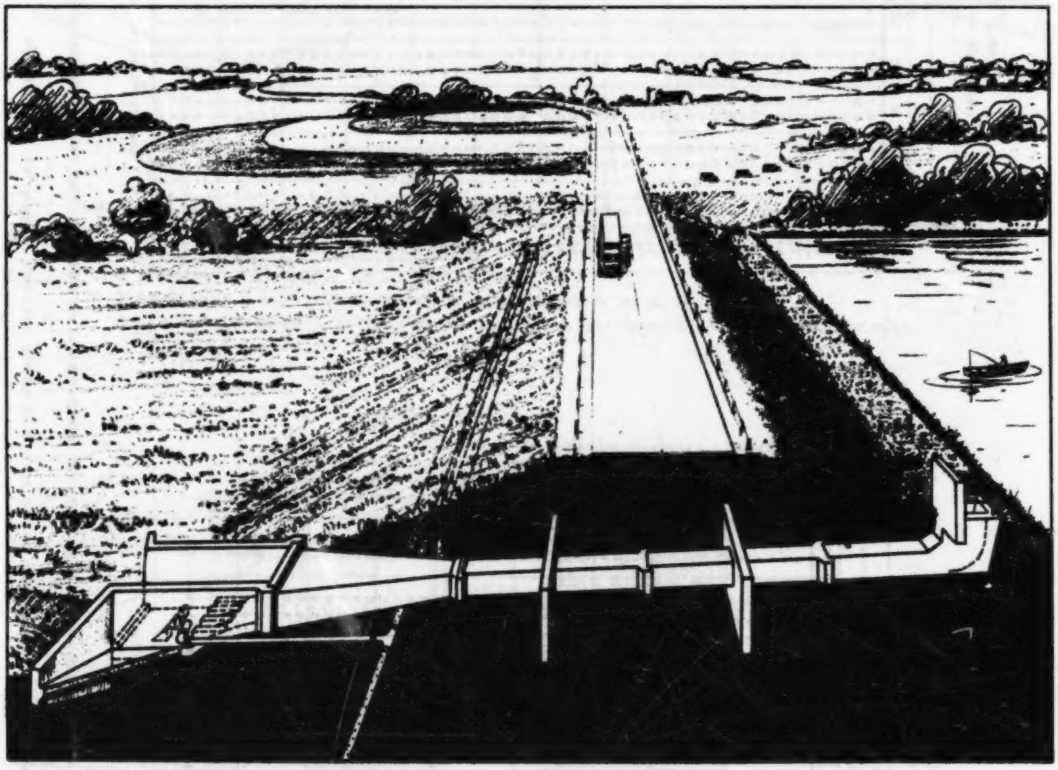
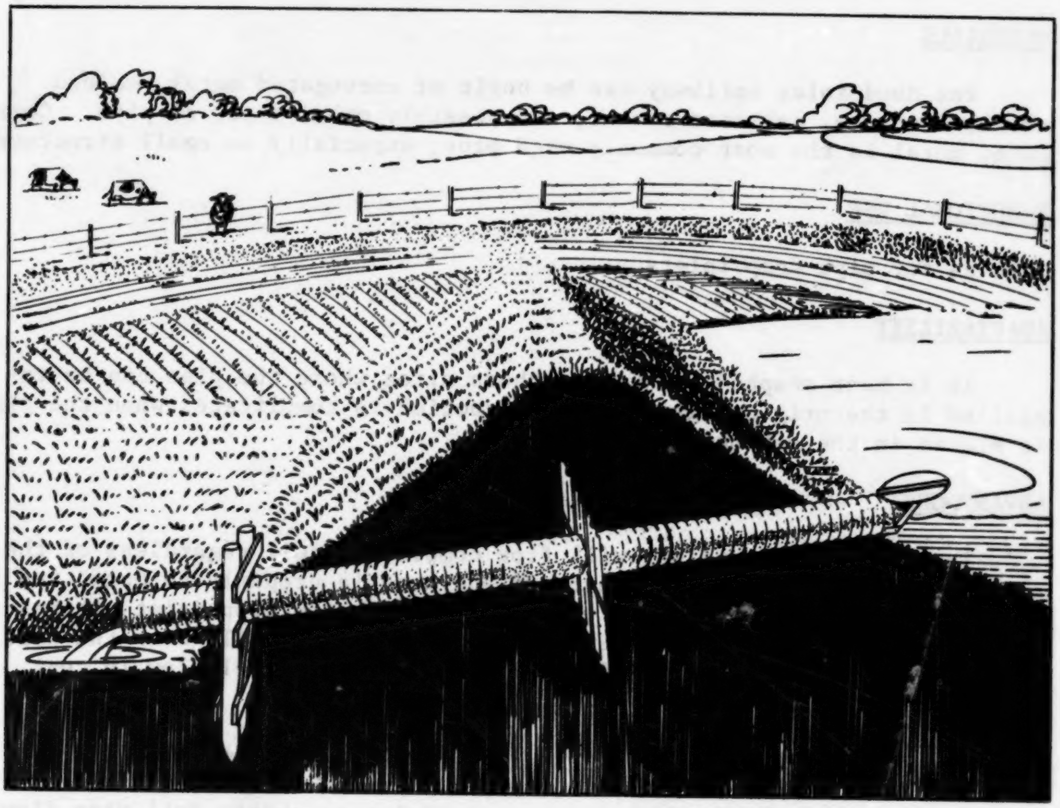


Figure 6-29 Reinforced concrete monolithic drop inlet spillway

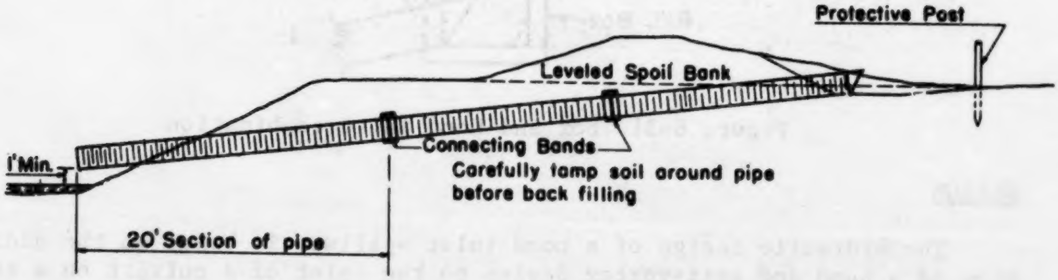
13. HOOD INLET SPILLWAY

DESCRIPTION

The hood inlet spillway consists of a pipe conduit with the inlet end formed by cutting the pipe at an angle. The long side of the cut is placed on top and figuratively forms a hood over the entrance. An anti-vortex wall or plate is located on the upper side of the pipe at the inlet. (Figure 6-30)



Metal pipe with hood inlet


Protective Post
Leveled Spoil Bank
Connecting Bands
Carefully tamp soil around pipe before back filling
1' Min.
20' Section of pipe

Hood inlet used to lower surface water into a channel

Figure 6-30 Hood inlet spillways

MATERIALS

The hood inlet spillway can be built of corrugated metal, welded steel, concrete, asbestos cement, and possibly other types of pipe. Corrugated metal is the most commonly used pipe, especially on small structures.

FUNCTIONAL USE

Same as for pipe drop inlets.

ADAPTABILITY

It is best adapted for use at those sites where the pipe can be installed in the original ground. Construction is complicated when the pipe is placed in the embankment.

ADVANTAGES

The hood inlet spillway will flow completely full regardless of the slope of the conduit if the length of the hood is properly selected and the head on the inlet is adequate. As compared with the drop inlet, it has the advantage that no riser is required and there is less fill over the pipe. It is simple to fabricate and install and is comparatively low in cost.

LIMITATIONS

For the same crest elevation, hooded pipes over 24 inches in diameter require a greater depth of water over the inlet to obtain full pipe flow than a pipe drop inlet. Icing presents a problem in some areas. Both of these may be overcome with a box and hood combination similar to the one shown in Figure 6-31.

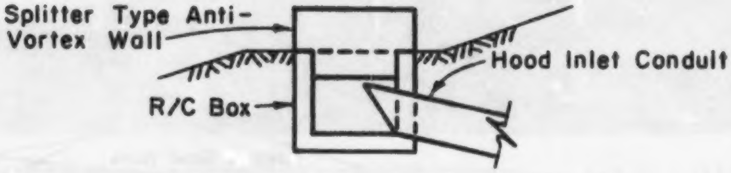
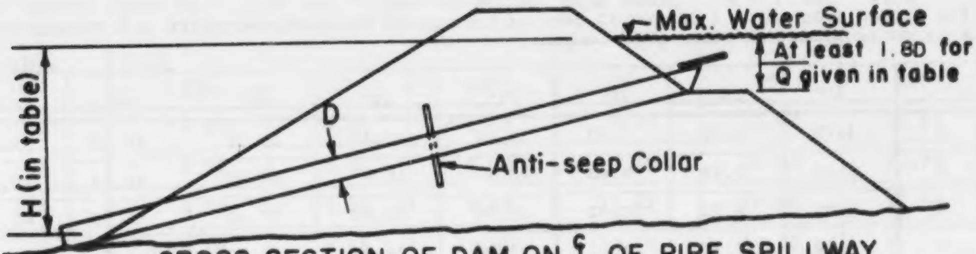


Figure 6-31 Box and hood inlet combination

DESIGN

The hydraulic design of a hood inlet spillway is based on the addition of a hood and anti-vortex device to the inlet of a culvert on a steep slope. These additions will make the culvert flow full when the water surface above the inlet (invert of the pipe) reaches about 1.8 times the diameter of the pipe. A capacity chart for 8- and 12-inch corrugated metal pipe, commonly used for farm ponds, can be found in Figure 6-32.



CROSS SECTION OF DAM ON ℄ OF PIPE SPILLWAY

CAPACITY TABLE OF HOODED INLET IN C.F.S. FOR VARYING HEADS						
	8" DIAMETER PIPE			12" DIAMETER PIPE		
Head H	For Pipe Lengths of: 50'	70'	90'	For Pipe Lengths of: 50'	70'	90'
5	1.8	1.6	1.4	5.0	4.4	4.0
6	2.0	1.7	1.5	5.5	4.8	4.4
7	2.1	1.9	1.7	6.0	5.2	4.7
8	2.3	2.0	1.8	6.3	5.6	5.0
9	2.4	2.1	1.9	6.7	5.9	5.4
10	2.6	2.2	2.0	7.1	6.2	5.6
11	2.7	2.3	2.1	7.4	6.5	5.9
12	2.8	2.4	2.2	7.8	6.8	6.2
13	2.9	2.5	2.3	8.1	7.1	6.4
14	3.0	2.6	2.3	8.4	7.4	6.7
15	3.1	2.7	2.4	8.7	7.6	6.9
16	3.2	2.8	2.5	9.0	7.9	7.1
17	3.3	2.9	2.6	9.2	8.1	7.3
18	3.4	3.0	2.7	9.5	8.4	7.6
19	3.5	3.0	2.7	9.8	8.6	7.8
20	3.6	3.1	3.0	10.0	8.8	8.0

Figure 6-32 Capacity chart for 8- and 12-inch C.M. pipe hood inlet spillway

Figure 6-33 provides capacities for larger corrugated metal pipe hood inlets. Capacities for smooth pipe can be found in Figure 6-34.

The use of some type of device to prevent vortex formation is necessary for developing maximum capacity shown in the previously mentioned figures. When the hood inlet is of corrugated metal pipe an anti-vortex device similar to the one shown in Figure 6-35 can be used.

PIPE FLOW CHART (Full flow assumed)

For Hooded Inlet K_e = 1.08 and 70 feet of Corrugated Metal Pipe Conduit, n = 0.025. Note corrections for other pipe lengths.

Dia. H	12"	15"	18"	21"	24"	30"	36"	42"
2	2.79	4.89	7.72	11.16	15.48	26.31	40.28	57.42
3	3.41	5.99	9.46	13.67	18.97	32.32	49.34	70.34
4	3.94	6.92	10.92	15.78	21.90	37.32	56.98	81.22
5	4.40	7.74	12.21	17.64	24.48	41.72	63.70	90.80
6	4.82	8.47	13.37	19.32	26.82	45.70	69.77	99.45
7	5.21	9.16	14.45	20.88	28.97	49.37	75.38	107.45
8	5.57	9.78	15.44	22.31	30.97	52.77	80.57	114.85
9	5.91	10.38	16.38	23.61	32.85	55.98	85.47	121.83
10	6.23	10.94	17.26	24.95	34.62	59.00	90.09	128.41
11	6.53	11.48	18.11	26.17	36.32	61.90	94.50	134.70
12	6.82	11.99	18.91	27.33	37.93	64.64	98.69	140.67
13	7.10	12.48	19.69	28.45	39.49	67.29	102.73	146.44
14	7.37	12.95	20.43	29.52	40.97	69.83	106.61	151.96
15	7.63	13.40	21.15	30.56	42.41	72.27	110.34	157.28
16	7.88	13.84	21.84	31.56	43.80	74.64	113.96	162.44
17	8.12	14.27	22.51	32.53	45.15	76.94	117.46	167.44
18	8.36	14.68	23.17	33.48	46.46	79.17	120.88	172.31
19	8.59	15.08	23.80	34.39	47.73	81.34	124.19	177.02
20	8.81	15.47	24.42	35.28	48.97	83.45	127.41	181.61
21	9.03	15.86	25.02	36.16	50.18	85.52	130.57	186.12
22	9.24	16.23	25.61	37.00	51.36	87.52	133.62	190.46
23	9.45	16.59	26.19	37.84	52.52	89.49	136.64	194.77
24	9.65	16.95	26.69	38.65	53.64	91.42	139.57	198.95
25	9.85	17.30	27.30	39.45	54.75	93.30	142.45	203.05
L	Correction Factors For Other Lengths							
40	1.23	1.21	1.19	1.18	1.16	1.13	1.12	1.10
50	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
60	1.06	1.06	1.05	1.05	1.04	1.04	1.04	1.03
70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
80	0.95	0.95	0.95	0.96	0.96	0.96	0.97	0.97
90	0.90	0.91	0.91	0.92	0.92	0.93	0.94	0.94
100	0.86	0.87	0.88	0.89	0.89	0.90	0.91	0.92

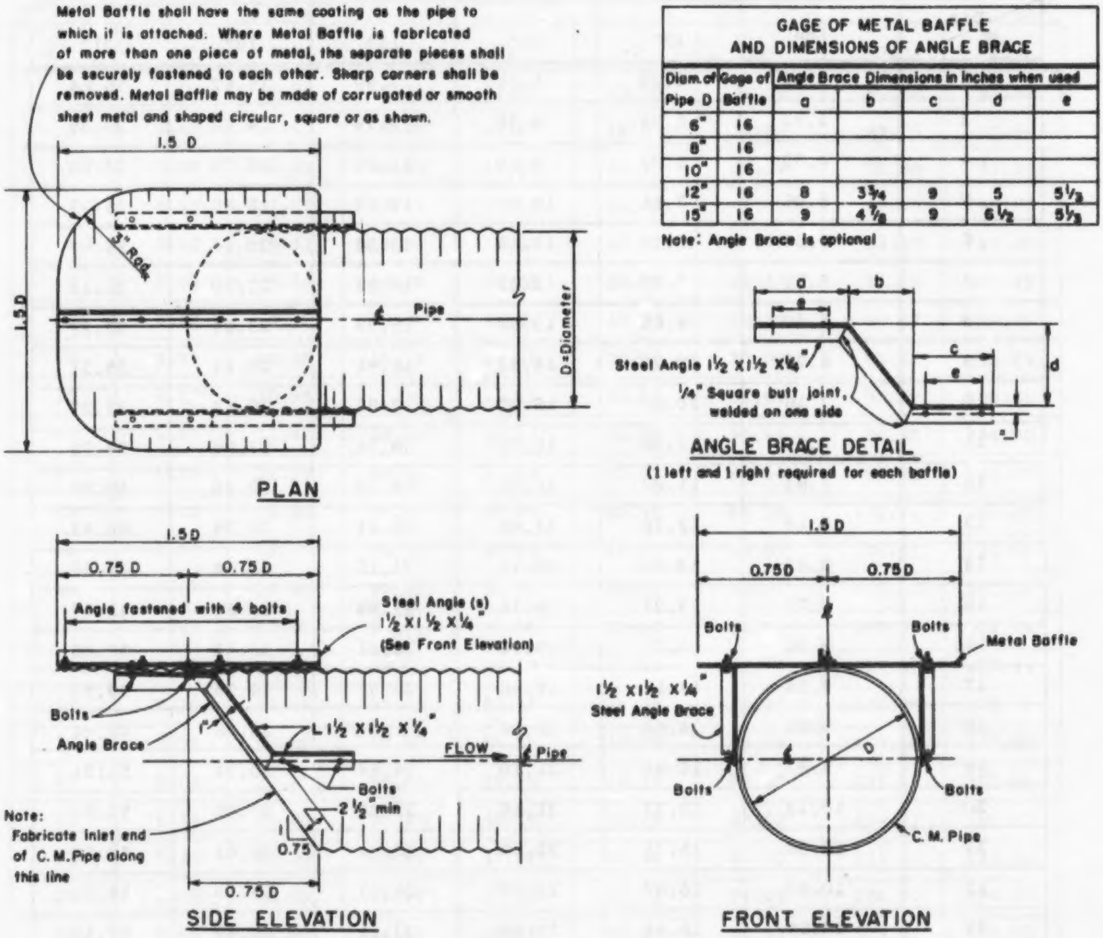
Figure 6-33 Pipe flow chart for corrugated metal pipe hood inlet spillway

PIPE FLOW CHART (Full flow assumed)

For Hooded Inlet $K_e = 1.08$ and 70 feet of smooth pipe conduit, $n = 0.010$. Note corrections for other lengths.

Dia. H	10"	12"	14"	15"	18"	21"
2	3.20	4.85	6.85	7.99	11.92	16.64
3	3.92	5.94	8.38	9.79	14.60	20.39
4	4.53	6.85	9.68	11.31	16.86	23.54
5	5.06	7.66	10.82	12.64	18.85	26.32
6	5.54	8.39	11.86	13.84	20.64	28.83
7	5.99	9.07	12.81	14.96	22.30	31.15
8	6.40	9.69	13.69	15.99	23.84	33.29
9	6.79	10.28	14.52	16.96	25.29	35.31
10	7.16	10.84	15.31	17.87	26.65	37.22
11	7.51	11.36	16.05	18.74	27.95	39.03
12	7.83	11.87	16.77	19.58	29.20	40.77
13	8.16	12.36	17.46	20.41	30.39	42.45
14	8.47	12.82	18.11	21.15	31.54	44.05
15	8.77	13.27	18.75	21.89	32.64	45.59
16	9.06	13.71	19.36	22.61	33.72	47.08
17	9.33	14.13	19.96	23.31	34.75	48.53
18	9.61	14.54	20.54	23.99	35.76	49.94
19	9.87	14.94	21.10	24.64	36.74	51.31
20	10.12	15.33	21.65	25.28	37.69	52.64
21	10.38	15.71	22.19	25.91	38.63	53.95
22	10.62	16.07	22.70	26.51	39.53	55.21
23	10.86	16.44	23.24	27.11	40.42	56.45
24	11.09	16.79	23.72	27.69	41.29	57.67
25	11.32	17.14	24.21	28.26	42.14	58.86
L	Correction Factors for Other Lengths					
40	1.11	1.09	1.08	1.08	1.06	1.05
50	1.07	1.06	1.05	1.05	1.04	1.03
60	1.03	1.03	1.02	1.02	1.02	1.02
70	1.00	1.00	1.00	1.00	1.00	1.00
80	0.97	0.97	0.98	0.98	0.98	0.98
90	0.95	0.95	0.96	0.96	0.96	0.97
100	0.93	0.93	0.94	0.94	0.95	0.96

Figure 6-34 Pipe flow chart for smooth pipe hood inlet spillway


1.5 D
1.5 D
3" Rad.
Pipe
D=Diameter
PLAN
1.5 D
0.75 D
0.75 D
Angle fastened with 4 bolts
Steel Angle (s)
1½ X 1½ X ¼"
(See Front Elevation)
Bolts
Angle Brace
L 1½ X 1½ X ¼"
FLOW
Pipe
Bolts
2½" min
1
0.75
Note:
Fabricate inlet end
of C. M. Pipe along
this line
0.75 D
SIDE ELEVATION
a
b
e
c
e
d
Steel Angle 1½ X 1½ X ¼"
¼" Square butt joint,
welded on one side
ANGLE BRACE DETAIL
(1 left and 1 right required for each baffle)
1.5 D
0.75 D
0.75 D
Bolts
Bolts
Metal Baffle
1½ X 1½ X ¼"
Steel Angle Brace
D
Bolts
Bolts
C. M. Pipe
FRONT ELEVATION

Metal Baffle shall have the same coating as the pipe to which it is attached. Where Metal Baffle is fabricated of more than one piece of metal, the separate pieces shall be securely fastened to each other. Sharp corners shall be removed. Metal Baffle may be made of corrugated or smooth sheet metal and shaped circular, square or as shown.

GAGE OF METAL BAFFLE
AND DIMENSIONS OF ANGLE BRACE

Diam. of Pipe D	Gage of Baffle	Angle Brace Dimensions in Inches when used				
		a	b	c	d	e
6"	16					
8"	16					
10"	16					
12"	16	8	3 3/4	9	5	5 1/3
15"	16	9	4 7/8	9	6 1/2	5 1/3

Note: Angle Brace is optional

Notes:

All bolts shall be 3/8" X 1½" with nut and split washers.
All holes for bolts shall be drilled 7/16" diameter.
All nuts, bolts and washers shall be galvanized, cadmium plated, or stainless steel.
All cuts shall be saw or shear cuts.
Holes in the angle brace shall be spaced and located to match corrugations in pipe and baffle.
Steel angles shall be galvanized.
All galvanizing damaged by cutting, drilling or welding shall be repaired by painting with two (2) coats of zinc dust-zinc oxide primer.

Figure 6-35 Details of a typical hood inlet and baffle for 6- to 15-inch diameter corrugated metal pipe

Under full pipe flow conditions, high velocities exist near the pipe entrance, which generally causes a scour hole in the embankment face unless protected by paving or riprap. It is, therefore, desirable to provide protection to prevent the formation of a scour hole under the inlet. Paving is better than riprap in that it prevents the growth of vegetation near the inlet where it is apt to impair the hydraulic efficiency of the spillway. Two typical paving layouts of inlets for farm pond spillways having barrel diameters of 12 inches or less are shown in Figure 6-36.

Where adequate riprap or paving is not available, or not apt to be installed, the lower two layouts can be used. These layouts should not be used where more than a thin film of ice might form around the inlet and be continuous with ice on the reservoir surface.

The inlet of the spillway must be located so that water can reach it from all sides. Some type of trash guard should be provided. Antiseep collars should be installed in the same manner as for drop inlet spillway.

14. EARTH SPILLWAYS

DESCRIPTION

An earth spillway (side or emergency spillway) is an open channel for conveying floodwater safely past an embankment from its reservoir to a point where its discharge will not damage the toe of the earth embankment. Refer to Chapter 11 of this manual for details of design, layout, and construction.

15. EARTH DAM

DESCRIPTION

The earth dam is an earth embankment constructed across a watercourse with adequate spillways to protect the dam from failure by overtopping from the design storm runoff. Because its construction involves use of natural, unprocessed materials, it is the most common type of dam. As its name implies, it is constructed of soil borrowed in the vicinity of the damsite. (Figure 6-37)

FUNCTIONAL USE

Earth dams with necessary spillways may be constructed to serve one or several intended purposes:

1. As a diversion dam to divert all or part of the water from a waterway or stream into a different watercourse, an irrigation canal, or a water-spreading system.

2. As a storage dam to store surface runoff for farm water supply, irrigation, municipal water supply, fish and wildlife or recreation, or to store sediment.

3. As a grade stabilization dam to drop water from one level to another.

4. As a retarding dam to store floodwater temporarily and protect land from flooding; or to reduce the outflow and permit the use of a more economical system of structures downstream.

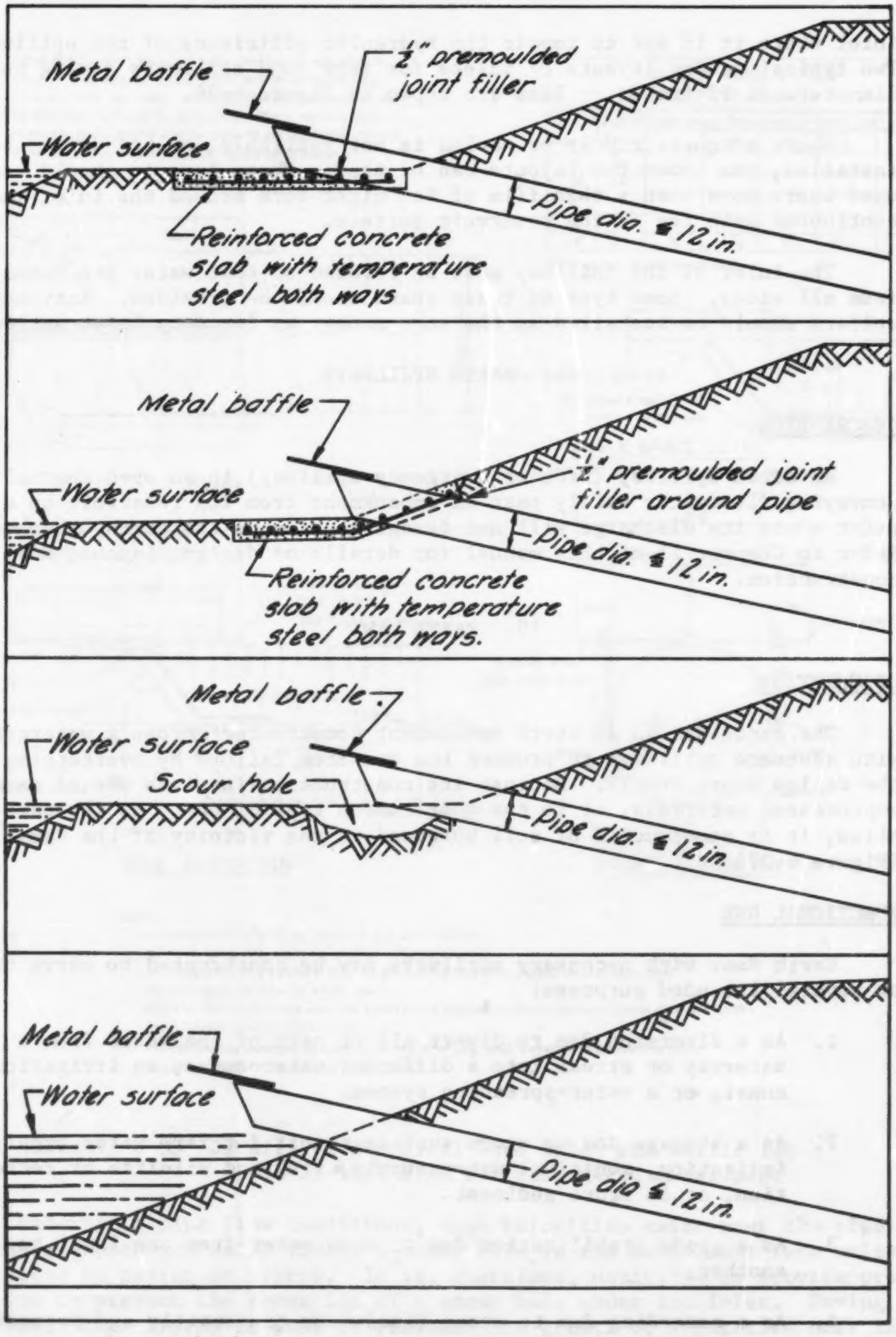

Metal baffle
½" premoulded joint filler
Water surface
Pipe dia. ≤ 12 in.
Reinforced concrete slab with temperature steel both ways
Metal baffle
½" premoulded joint filler around pipe
Water surface
Pipe dia. ≤ 12 in.
Reinforced concrete slab with temperature steel both ways.
Metal baffle
Water surface
Scour hole
Pipe dia. ≤ 12 in.
Metal baffle
Water surface
Pipe dia ≤ 12 in.

Figure 6-36 **Typical layouts of inlets for 12-inch or less hood inlet spillways**

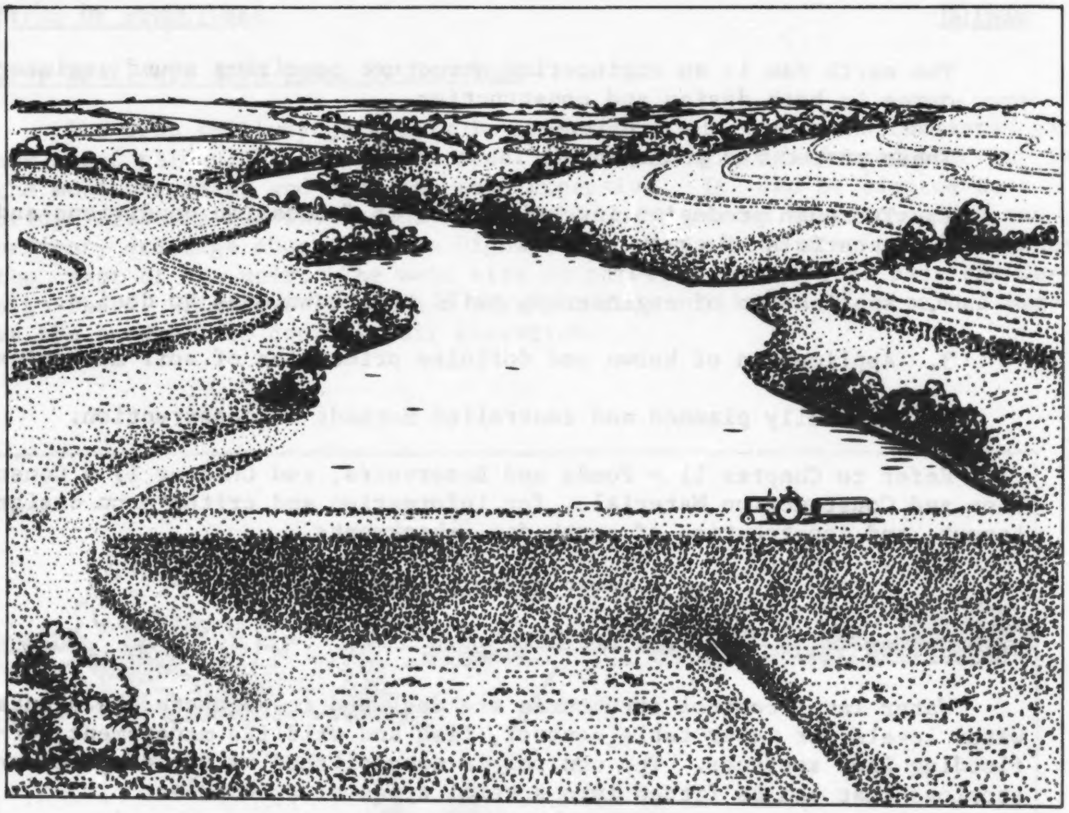


Figure 6-37 Earth dam
Note outlet of principal spillway in foreground
and vegetated earth spillway around embankment

ADAPTABILITY

Earth dams are adapted to any gully or valley site where the soils are suitable, the banks and valley side slopes are high enough to permit the construction of an earth embankment, and there is a safe spillway location.

ADVANTAGES

With proper design and construction, the earth dam is a reliable and dependable structure and for most sites the most economical structure for the intended purpose.

LIMITATIONS

It is limited only by topographic and foundation conditions and availability of suitable earthfill material.

DESIGN

The earth dam is an engineering structure requiring sound engineering procedures in both design and construction.

These procedures include:

1. Thorough predesign investigations of foundation conditions and materials of construction.
2. Application of engineering skill and techniques to design.
3. Application of known and definite principles of soil mechanics.
4. Carefully planned and controlled methods of construction.

Refer to Chapter 11 - Ponds and Reservoirs, and Chapter 17 - Constru-tion and Construction Materials, for information and criteria on design, layout, and construction of earth dam embankments.

16. WATER CONTROL STRUCTURES

DESCRIPTION

Water level control structures are designed to regulate and maintain water levels for water table control, fish and wildlife management, or for flooding land surfaces. The control is accomplished by use of gates or stoplogs that can be fitted into several types of structures.

USES

1. Control drainage. To maintain a high water table consistent with the crop by reducing the depth of normal drainage. With uncontrolled drainage, the water table generally drops during the hot, dry weather toward the end of the season. Also, to control the water table in peat and muck to reduce subsidence.
2. Subirrigation. Subirrigation is similar to controlled drainage but differs in that water is supplied from an outside source to maintain or regulate the water table throughout the growing season.
3. Flooding. Flooding of the land surface is necessary in the production of some crops such as cranberries and rice. It is also used to create habitat for some species of wildlife.
4. Water level regulation. The manipulation of water levels for the management of fish spawning areas and water fowl habitat.

TYPES OF STRUCTURES

Drop Spillways with Gates or Stoplogs

The drop spillway generally is constructed of reinforced concrete, timber sheet piling, or corrugated steel sheet piling. Reinforced concrete is the most permanent and also the most expensive. It can be adapted to a bridge crossing and the height and width can be varied to accommodate any ordinary drainage channel. The highest position of the stoplogs determines the crest of the weir. The weir size is normally selected to pass the design storm. Figure 6-38 shows a straight drop spillway with stoplogs used as the headwall to control weir elevation.

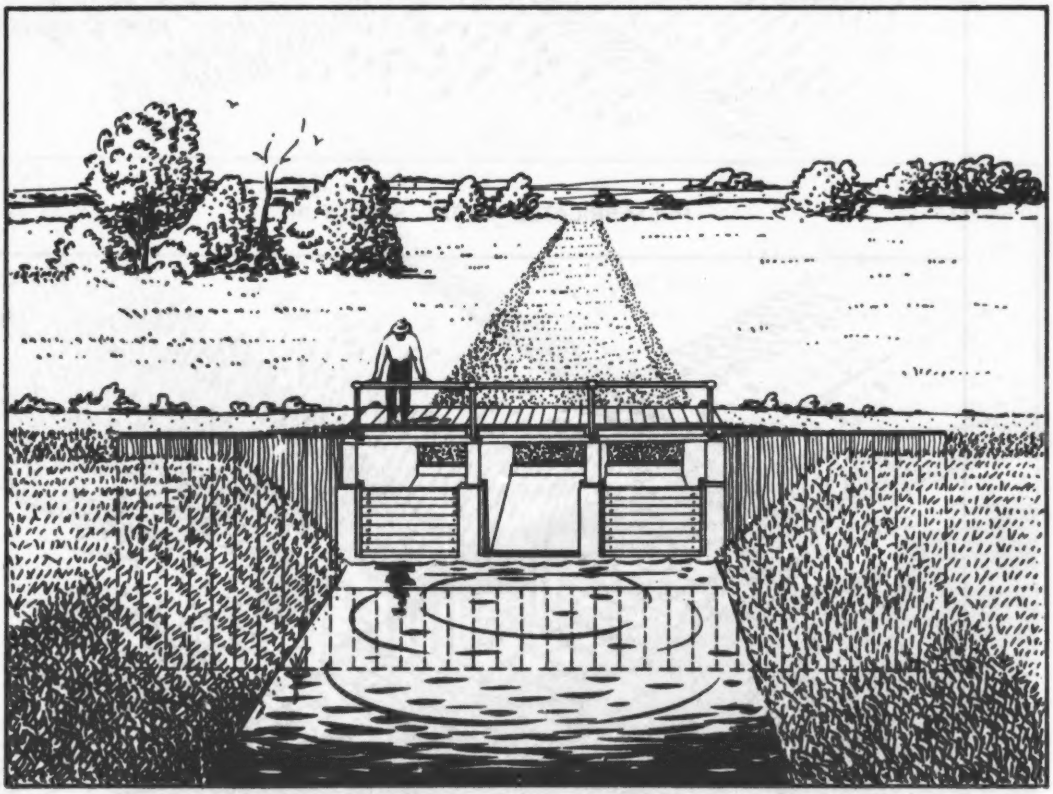
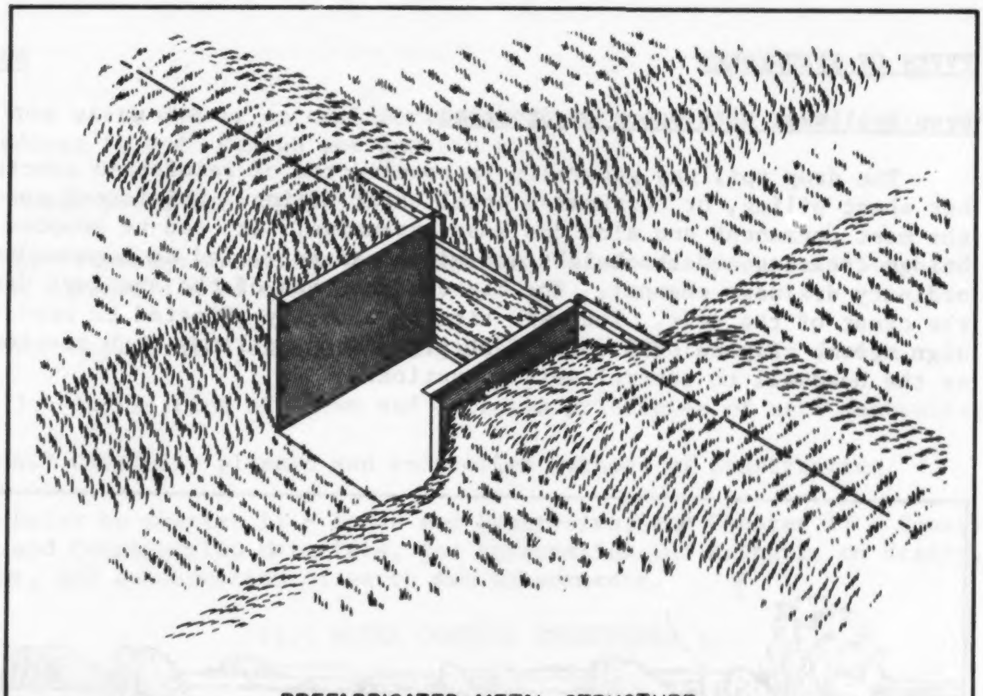


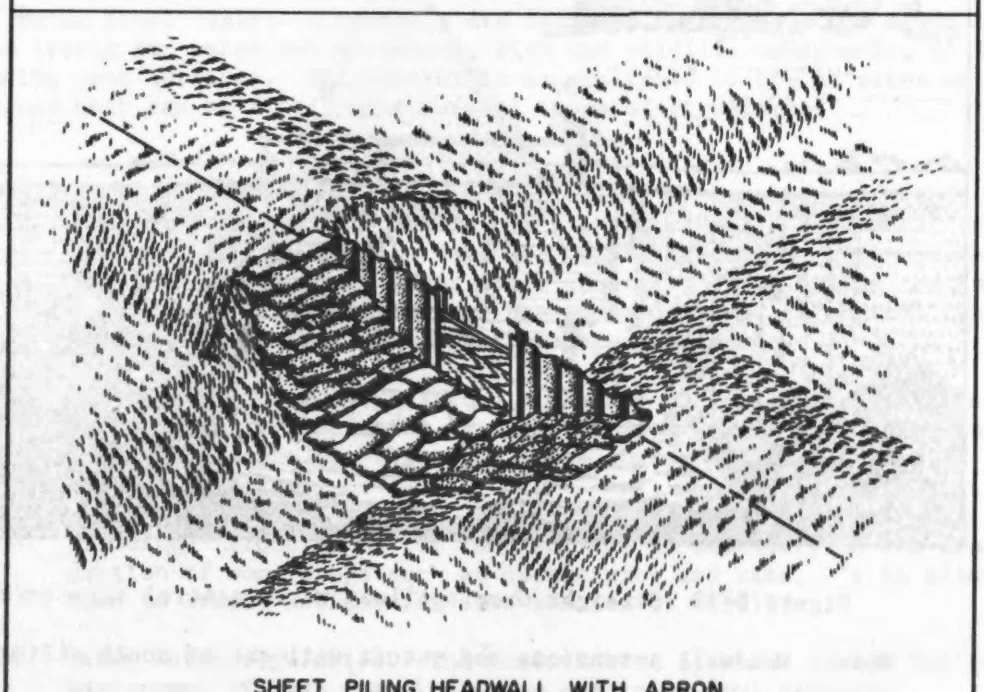
Figure 6-38 Straight drop spillway water control structure

Note: Headwall extensions and cutoff wall are of sheet piling

Sheet piling structures are often used for sites with poor foundation or extremely wet conditions. Sheet piling spillways require the use of special equipment to drive or jet the piling into place. Treated lumber is recommended for long life. In any event, only first-class lumber should



PREFABRICATED METAL STRUCTURE



SHEET PILING HEADWALL WITH APRON AND SIDEWALLS OF SAND-CEMENT BAGS

Figure 6-39 Small low cost water control structures

be used. Steel sheet piling makes a permanent structure if properly installed and protected. The cost is similar to reinforced concrete. A low-cost structure consisting of a sheet piling wall, an opening into which stoplogs are placed, and the apron and sidewalls built of sand-cement bags, is shown in Figure 6-39. This structure is well adapted to V-type ditches 1.5 to 2.0 feet deep or small trapezoidal ditches commonly used for subirrigation or in wildlife areas. Also shown in Figure 6-39 is one type of prefabricated sheet metal structure that is easy to install and can be moved.

Box Inlet on Culvert with Gate or Stoplogs

This structure combines a road culvert with a water control structure. The culvert may be of concrete, corrugated metal pipe or timber. The box inlet section is generally made of reinforced concrete, timber, or a half-section of metal pipe. An example of this type of structure is shown in Figure 6-40.

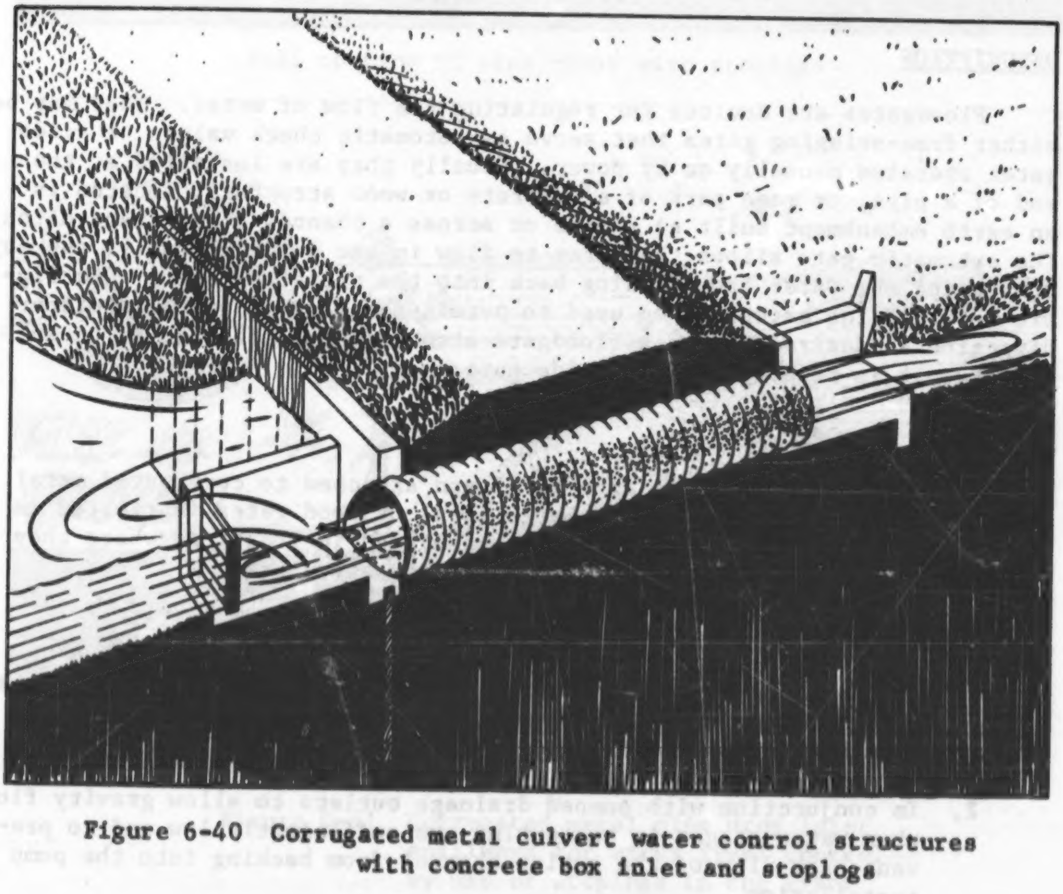


Figure 6-40 Corrugated metal culvert water control structures with concrete box inlet and stoplogs

Drop Inlet Spillway with Stoplogs

The pipe drop inlet spillway can be used with an earth dam embankment to impound and control the depth of water by use of stoplogs placed inside the drop inlet. Examples of a full section metal pipe riser and a half section metal pipe riser are shown in Figure 6-41.

Drop Inlet Spillways for Fish Management

By incorporating additional features in the drop inlet spillways, fish management can be provided. Figure 6-42 shows necessary provisions to permit migration of fish upstream through the structure, or provide for cool water release from a reservoir for fish below the structure.

Open Flumes

This is a box-type structure with the top side open and stoplogs or a gate installed at the upstream end for controlling the water level. It is generally constructed of concrete, timber or metal. See Figure 6-43.

17. FLOODGATES

DESCRIPTION

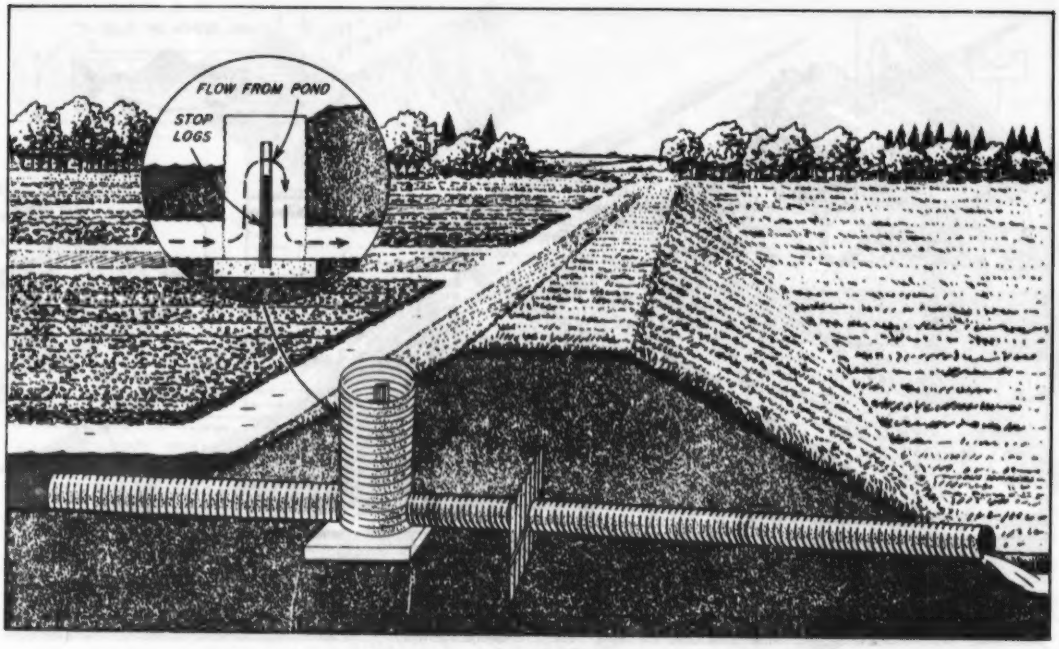
Floodgates are devices for regulating the flow of water. They may be either free-swinging gates that serve as automatic check valves or slide gates operated manually or by power. Usually they are installed at the end of a pipe, or made part of a concrete or wood structure, located in an earth embankment built as a dike or across a channel or drainage ditch. The automatic gate allows the water to flow in one direction only, thereby preventing the water from flowing back into the protected area. See Figure 6-44. Slide gates may be used to permit the flow of water in either direction as desired. When a floodgate structure outlets into an ocean estuary, it is referred to as a tide gate.

MATERIAL

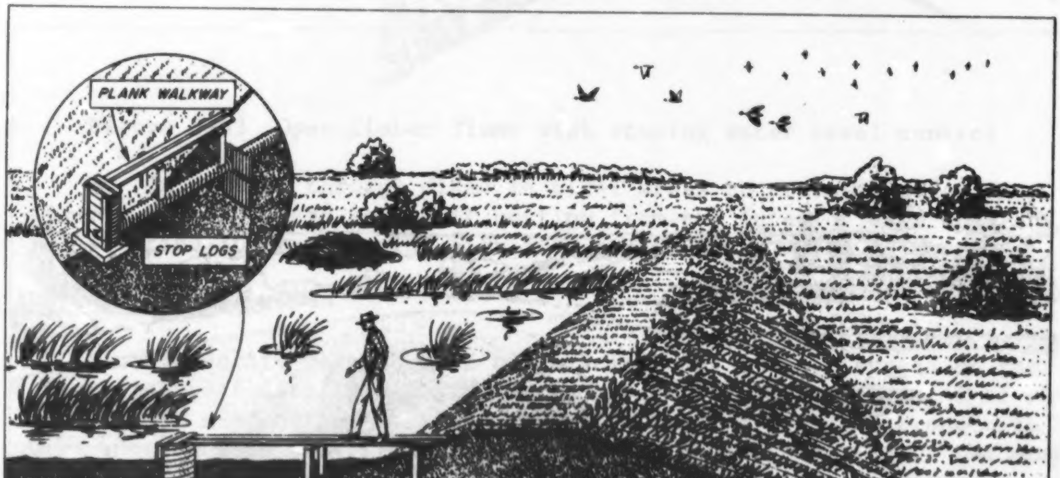
Manufactured gates made from metal and attached to corrugated metal pipes are the most widely used. Large metal or wood gates fabricated in both round and rectangular shapes are often used in locations where they can be installed as part of a wood or concrete structure.

FUNCTIONAL USES

1. At the end of a drainage ditch or flood channel where it outlets into a larger stream to prevent high stages on the large stream from backing up the ditch or channel.
2. In conjunction with pumped drainage outlets to allow gravity flow when water stages in the outlet are sufficiently low and to prevent high flow of the outlet channel from backing into the pump installation.

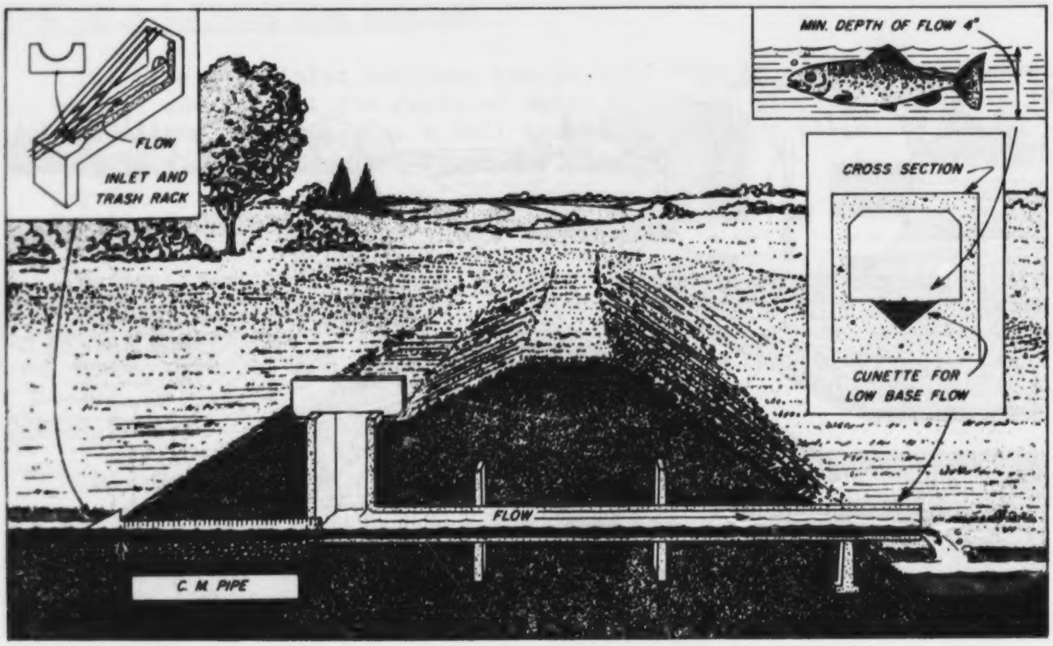

FLOW FROM POND
STOP LOGS

Full section of pipe riser with stoplogs

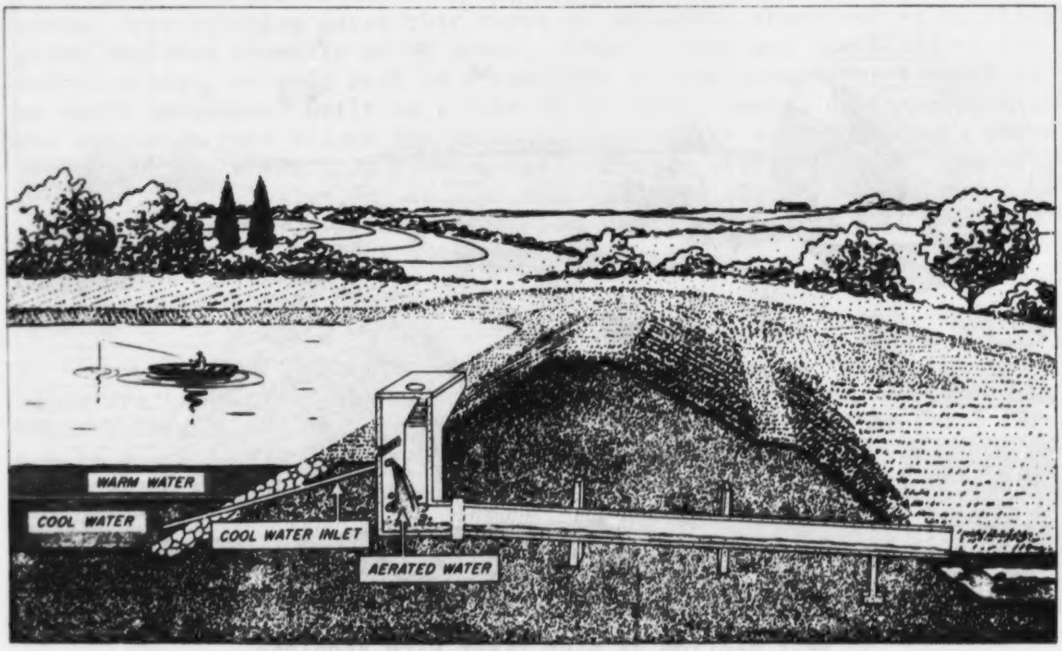

PLANK WALKWAY
STOP LOGS

Half section of pipe riser with stoplogs

Figure 6-41 Corrugated metal pipe drop inlet spillways for water level control by use of stoplogs in the riser


INLET AND
TRASH RACK
FLOW
MIN. DEPTH OF FLOW 4"
CROSS SECTION
CUNETTE FOR
LOW BASE FLOW
FLOW
C. M. PIPE

Migration of fish upstream through structure


WARM WATER
COOL WATER
COOL WATER INLET
AERATED WATER

Cool water release for fish below structure

Figure 6-42 Monolithic reinforced concrete drop inlet with provisions for fish management

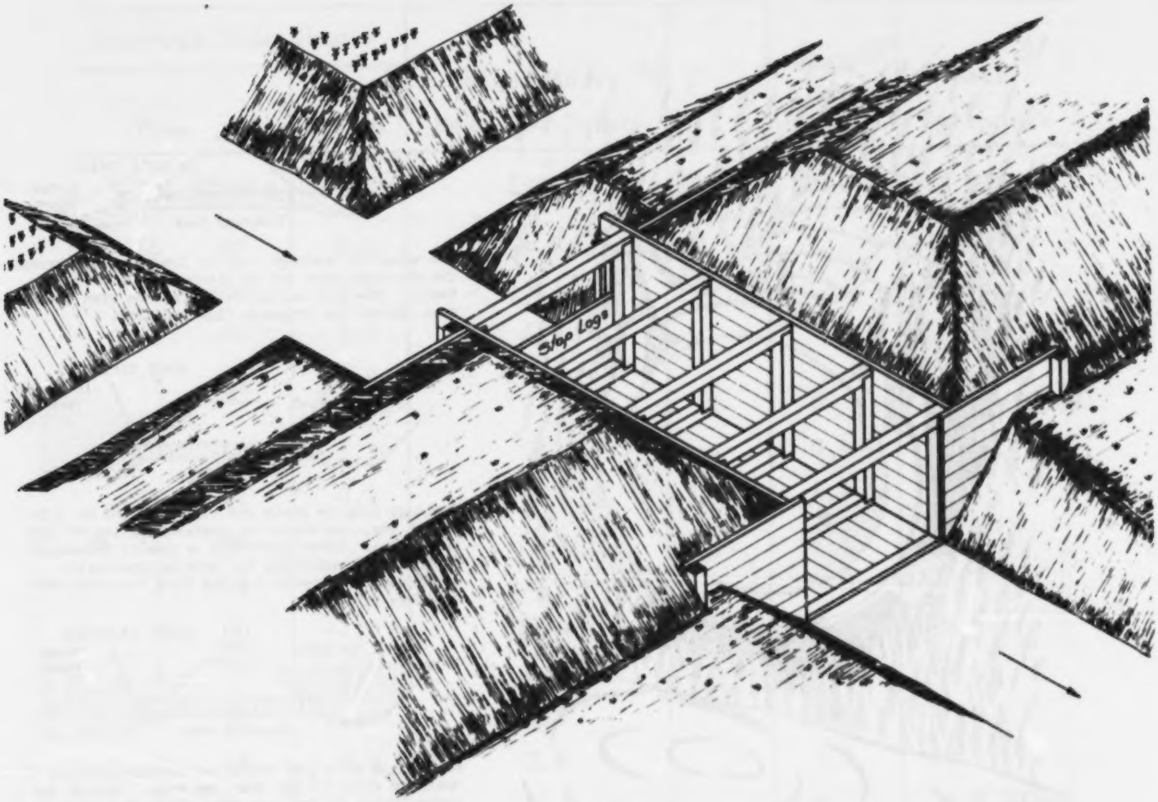


Figure 6-43 Open timber flume with stoplog water level control

3. In outlets through dikes in tidal areas to prevent inflow from the tides and to permit outflow from the interior area when the tide lowers. During high tide the interior water is stored.

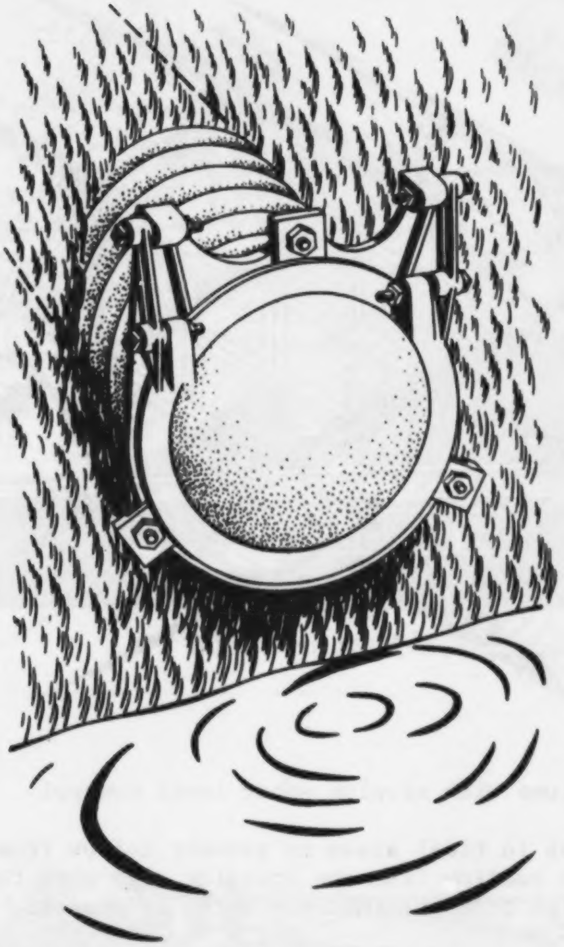
ADAPTABILITY

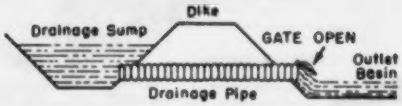
Floodgates are best adapted to locations where water stages on the outlet side periodically are low enough to permit gravity disposal of runoff water in a specified period of time. They also are used along with pumps where enough gravity flow will occur to reduce the size of the pumps required or the amount of time the pumps must be operated.

ADVANTAGES

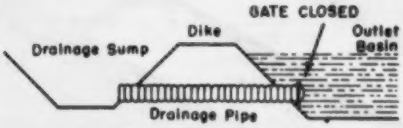
The variety of sizes and types available permits fitting them to site requirements. Floodgates installed with pumping plants reduce the cost of operation of the plant. Floodgates may be used to prevent flooding of protected land and in some cases may eliminate the need for pumping.

They can be installed with inlet controls to maintain a definite water elevation for subirrigation, reducing subsidence of organic soils, or for providing water areas for wildlife developments.

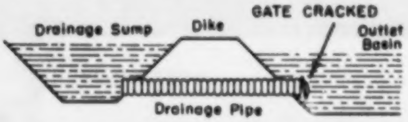




The water in drainage sump is free to flow through the drainage pipe and be discharged into outlet basin. The gate automatically stands open to whatever degree the drainage flow requires.



Drainage sump is empty and tide or flood head in outlet basin is above the drainage outlet so that the gate is either partially or wholly submerged. Under these conditions the gate automatically remains closed preventing any back flow into the drainage system.



High flood in outlet basin and an accumulation of drainage water in the drainage sump. Should the accumulation in drainage sump reach an elevation higher than the flood or tide in outlet basin the gate automatically becomes "cracked" sufficiently to permit the drainage flow to proceed until the drainage head equals the tide or flood head in outlet basin. The gate then automatically closes and remains closed until the drainage head again exceeds the tide or flood head in outlet basin.

Figure 6-44 Automatic swinging floodgate

LIMITATIONS

Floodgates must be protected from debris that could cause breakage or impair their use. They must be inspected frequently and maintained in good repair. Automatic gates especially require maintenance to insure that they open and close as required. In many cases, site conditions require extensive dewatering work if large wood or concrete structures are to be installed with gates. Riprap or concrete headwalls are frequently required to prevent erosion around the gate.

DESIGN

1. Normally, the design of the outlet system should be based on the same drainage coefficients as apply to adjoining nontidal lands. However, the effects of prolonged wind tides or river floodflows may require a high degree of protection from flooding in the

Observed Tide Stages							
Time			Gage Height	Height Above 1/ Mean Low Water	2/ E	Head 3/ on Gate	4/ Gate Discharge
	Hour	Minute	Feet	Feet	Feet	Feet	cfs
AM	6	02	3.0	4.7	3.8		
	7	00	3.8	5.5 = R			
	8	00	3.5	5.2			
	9	00	2.8	4.5			
						0	0 @ 9H36M
	10	00	1.5	3.2		0.6	18.3
	11	01	0.2	1.9		1.9	32.5
M	12	00	-1.0	0.7		3.1	41.6
	1	02	-1.7	0.0		4.0	47.2
	2	00	-1.6	0.1		3.9	46.6
	3	00	-1.3	0.4		3.4	43.6
	4	00	-0.5	1.2		2.6	37.9
	5	00	0.9	2.6		1.2	25.9
						0	0 @ 5H36M
	5	58	2.2	3.9			
	7	00	3.5	5.2			
	8	00	3.7	5.4			
PM	9	00	3.2	4.9			

1/ Mean low water = elevation -1.7   R = tidal range

2/ Distance of design water elevation in gate forebay above mean low water (0.0 on tidal range)

3/ Head on gate = E less height above mean low water

4/ Discharge for selected 30" Ø gate from Figure 6-46

Figure 6-45 Tide gate design data

protected area. See the State Standards and Specifications for guidance.

2. The highest allowable water surface above the levee should be used as the basis for the hydraulic design.

3. The data may be determined by direct observation at the site or obtained from recorded data obtained nearby. This data may be recorded as shown in Figure 6-45, Tide gate design data.

4. By means of Figure 6-46, Capacity of circular gates, determine the gate discharges for the various heads on the gate.

5. Plot a time-gate discharge curve and determine the area under the curve. This represents the total discharge for the tidal cycle.

6. Divide the total discharge by the total time of the cycle to obtain the average rate of discharge for the gate size selected.

7. If the selected gate size does not meet the discharge requirements determined in item 1, recalculate for other gate sizes or use of multiple gates.

Complex or large installations require the assistance of an engineer.

18. IRRIGATION STRUCTURES

Structures play an important part in the use and management of irrigation water, whether by open ditch or pipeline. Various kinds of structures are used for the storage, diversion, distribution and conveyance of water, and for erosion and grade control. For more detailed information on irrigation structures refer to Chapter 3 - Planning Farm Irrigation Systems, Section 15, N.E.H. and Standard plans developed by the States. Most large storage, diversion, and conveyance structures require the assistance of an engineer.

STORAGE STRUCTURES

Structures for storing irrigation water are classified as reservoirs for runoff storage, offstream storage, seepage storage and regulating storage.

Runoff Storage

Reservoirs for storing runoff water generally are made by constructing an earth dam across a watercourse. (See Figure 6-37) They will vary in size from small excavated farm ponds to large impounding main stream reservoirs. Usually large reservoirs are built to furnish water to a group or groups of farmers through a legal organization, such as an irrigation or conservancy district. Small farm ponds usually are built for use on single farms or fields.

Gate Size - Inches	12	14	15	16	18	20	21	24	30	36	42	48	54
Gate Area - Sq. Ft.	.79	1.07	1.23	1.40	1.77	2.18	2.41	3.14	4.91	7.07	9.62	12.57	15.90
Hydr. Head - Feet													
.2	1.70	2.30	2.64	3.01	3.81	4.69	5.18	6.75	10.56	15.20	20.68	27.03	34.19
.4	2.40	3.25	3.74	4.26	5.38	6.63	7.33	9.55	14.95	21.54	29.32	38.31	48.47
.6	2.94	3.98	4.58	5.21	6.58	8.11	8.97	11.68	18.27	26.30	35.79	46.76	59.15
.8	3.40	4.60	5.29	6.02	7.61	9.37	10.36	13.50	21.11	30.40	41.37	54.05	68.37
1.0	3.80	5.15	5.92	6.73	8.51	10.49	11.59	15.10	23.62	34.01	46.27	60.46	76.48
1.2	4.16	5.64	6.48	7.38	9.34	11.49	12.70	16.55	25.88	37.26	50.70	66.24	83.79
1.4	4.49	6.08	6.99	7.95	10.05	12.38	13.69	17.84	27.89	40.16	54.64	71.40	90.31
1.6	4.65	6.30	7.24	8.25	10.43	12.84	14.19	18.49	28.92	41.64	56.66	74.04	93.65
1.8	5.10	6.91	7.95	9.04	11.43	14.08	15.57	20.28	31.72	45.67	62.15	81.20	102.71
2.0	5.37	7.28	8.36	9.52	12.04	14.82	16.39	21.35	33.39	48.08	65.41	85.48	108.12
2.2	5.64	7.64	8.78	10.00	12.64	15.57	17.21	22.42	35.06	50.48	68.69	89.75	113.53
2.4	5.89	7.98	9.18	10.44	13.20	16.26	17.98	23.42	36.63	52.74	71.77	93.77	118.61
2.6	6.13	8.30	9.53	10.84	13.69	16.85	18.62	24.24	37.87	54.50	74.13	96.85	122.49
2.8	6.36	8.61	9.90	11.27	14.25	17.55	19.40	25.28	39.53	56.91	77.44	101.19	128.00
3.0	6.58	8.91	10.25	11.66	14.74	18.16	20.08	26.16	40.90	58.89	80.13	104.71	132.45
3.2	6.80	9.21	10.59	12.05	15.24	18.77	20.75	27.04	42.28	60.87	82.83	108.23	136.90
3.4	7.01	9.49	10.91	12.42	15.70	19.34	21.38	27.85	43.55	62.71	85.33	111.50	141.03
3.6	7.21	9.77	11.23	12.78	16.16	19.90	22.00	28.67	44.83	64.55	87.83	114.76	145.17
3.8	7.41	10.04	11.54	13.13	16.60	20.45	22.61	29.45	46.06	66.32	90.24	117.92	149.14
4.0	7.60	10.29	11.83	13.47	17.03	20.97	23.18	30.21	47.23	68.01	92.54	120.93	152.96
4.2	7.79	10.55	12.13	13.80	17.45	21.49	23.76	30.96	48.41	69.71	94.85	123.95	156.77
4.4	7.97	10.88	12.41	14.13	17.86	22.00	24.32	31.68	49.54	71.34	97.07	126.83	160.43
4.6	8.15	11.04	12.69	14.45	18.27	22.50	24.87	32.40	50.67	72.96	99.28	129.72	164.09
4.8	8.33	11.28	12.96	14.76	18.66	22.98	25.40	33.10	51.75	74.52	101.39	132.49	167.59
5.0	8.50	11.51	13.23	15.06	19.05	23.46	25.93	33.79	52.83	76.07	103.51	135.25	171.08
5.2	8.67	11.74	13.49	15.36	19.42	23.91	26.44	34.45	53.86	77.56	105.53	137.89	174.42
5.4	8.83	11.96	13.75	15.65	19.79	24.37	26.94	35.11	54.89	79.04	107.55	140.53	177.76
5.6	9.00	12.19	14.01	15.95	20.16	24.83	27.45	35.76	55.92	80.53	109.57	143.17	181.10
5.8	9.16	12.40	14.26	16.23	20.51	25.27	27.93	36.39	56.91	81.94	111.50	145.69	184.28
6.0	9.31	12.60	14.49	16.49	20.85	25.68	28.39	36.99	57.84	83.28	113.32	148.07	187.30
6.2	9.46	12.82	14.74	16.77	21.20	26.12	28.87	37.62	58.82	84.70	115.25	150.59	190.48
6.4	9.61	13.02	14.97	17.04	21.54	26.53	29.33	38.21	59.75	86.04	117.08	152.98	193.50
6.6	9.76	13.23	15.20	17.30	21.88	26.94	29.79	38.81	60.69	87.39	118.90	155.37	196.52
6.8	9.91	13.43	15.44	17.57	22.21	27.36	30.25	39.41	61.62	88.73	120.73	157.75	199.55
7.0	10.06	13.62	15.66	17.82	22.53	27.75	30.68	39.97	62.50	90.00	122.46	160.02	202.41
7.2	10.20	13.81	15.88	18.07	22.85	28.14	31.11	40.54	63.39	91.27	124.19	162.28	205.27
7.4	10.34	14.01	16.10	18.33	23.17	28.54	31.55	41.10	64.27	92.55	125.93	164.54	208.13
7.6	10.48	14.20	16.32	18.58	23.49	28.93	31.98	41.67	65.16	93.82	127.66	166.80	210.99
7.8	10.62	14.38	16.53	18.82	23.79	29.30	32.39	42.20	65.99	95.02	129.29	168.94	213.70
8.0	10.75	14.56	16.74	19.05	24.09	29.67	32.80	42.74	66.83	96.22	130.93	171.08	216.40

Based on $Q = .6 A \sqrt{2gh}$ - Pipe Flowing Full with Outlet Submerged

Figure 6-46 Capacity of circular gates

Offstream Storage

Offstream storage should be considered if streamflow is not enough to provide the required amount of irrigation water or if damming a stream is not feasible. Floodflow in the stream may be diverted through a pipe or open ditch or pumped into an offstream reservoir. The reservoir is made by constructing an earth dam across a draw or small valley or by building a levee around an area of land.

Seepage Storage

Excavated reservoirs for intercepting and storing underground seepage water may be used in some localities as a water supply for irrigating small areas. The storage basin usually is excavated in a low-lying level area where the lateral movement of water underground replenishes the supply. A dependable excavated reservoir requires a high natural water table under adjacent lands and a highly pervious layer permitting the rapid lateral movement of water within practical excavated depths, usually 12 to 20 feet. The success of such a reservoir depends upon the rate of recharge because its capacity generally is small.

Regulating Storage

Regulating reservoirs are used where the stream is too small for continuous irrigation. They are built either by excavating a pit and using the spoil material to build a levee around it, or by building an earthen dam across a low area. Size is generally determined by the amount of water needed for one day's operation. The reservoir should be large enough to store all inflow while the irrigation system is not in operation. Irrigation water may be supplied by pumping from a low-producing well, diverting flow from a spring, or continuous small deliveries from canals and laterals. Often it is called an overnight-storage reservoir.

DIVERSION STRUCTURES

Where surface irrigation is practiced, the source of water is often the direct diversion of flow from a natural stream into a conveyance canal or ditch. Although temporary measures may be used to divert the water, a good system will use a permanent structure to raise the water level in the stream and force part of the flow into the irrigation ditch. Many types of structures are used for this purpose. The most common is one that uses stoplogs to adjust water levels and the diversion of flow.

Figure 6-47 shows a stoplog type of concrete structure used on creeks and small streams. Many states use various versions of standard plans for this type of structure. Some stoplog structures have provisions for a pump installation. These are used where water must be raised above the level of the stream or where the water is moved directly into a sprinkler system. Diversion structures used on wide stream subject to high floodflows may require provisions for the collapse of sections of the structure during the periods of high water to safely pass the floodflows.

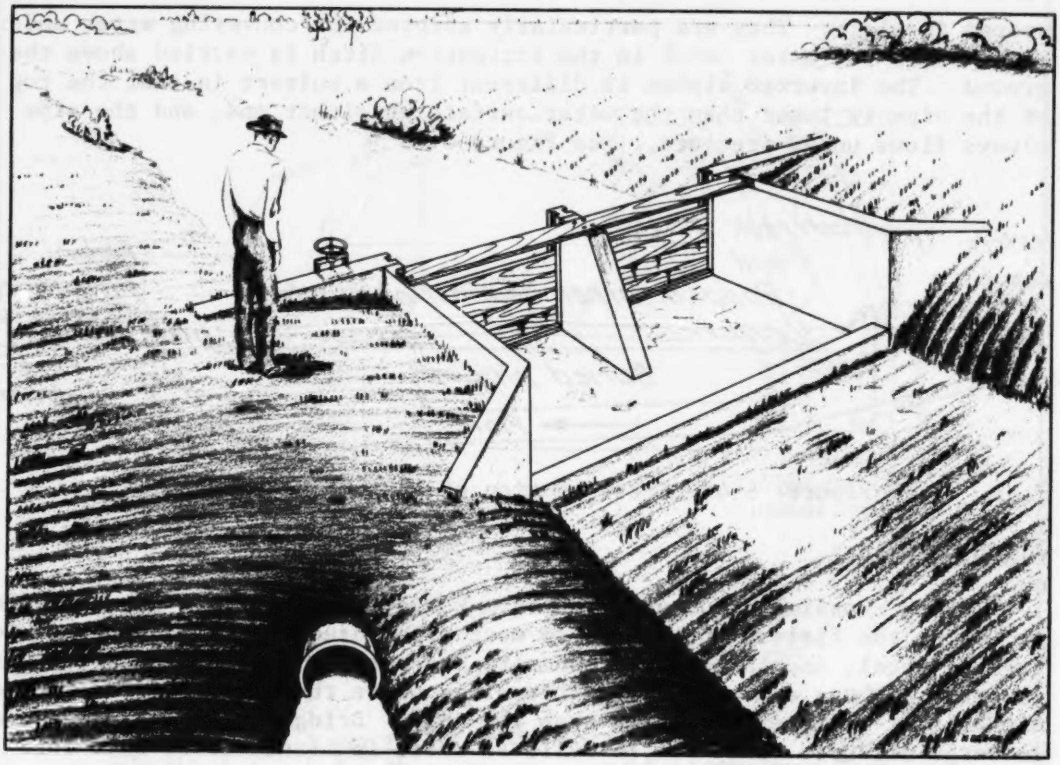


Figure 6-47 Stoplog type concrete diversion structure

DITCH CONVEYANCE STRUCTURES

Conveyance structures are used to transport water across or under obstructions, such as swales, draws, or roads, and to convey it along steep hillsides. They include flumes, inverted siphons, road culverts, and bridges.

Flumes

Flumes are artificial channels, supported by a substructure, for carrying water across areas where ditches are not practical. They are used to carry the water across draws or swales or to convey it along steep or rocky hillsides. These structures must have the capacity to carry the full discharge of the ditch, and the substructure must be strong enough to support the flume when flowing full. Timber, metal, or concrete are ordinarily the materials used for open flumes. Long span steel pipes may be used as a closed flume.

Inverted Siphons

An inverted siphon is a closed conduit with each end raised to form a U-shaped structure for carrying water under streams and drains or under roads and other obstructions. Inverted siphons usually are constructed of corrugated or smooth metal pipe, concrete pipe or reinforced concrete poured in place. They are particularly adapted for conveying water under roads where the water level in the irrigation ditch is carried above the ground. The inverted siphon is different from a culvert in that the top of the pipe is lower than the water surface at either end, and the pipe always flows under pressure. See Figure 6-48

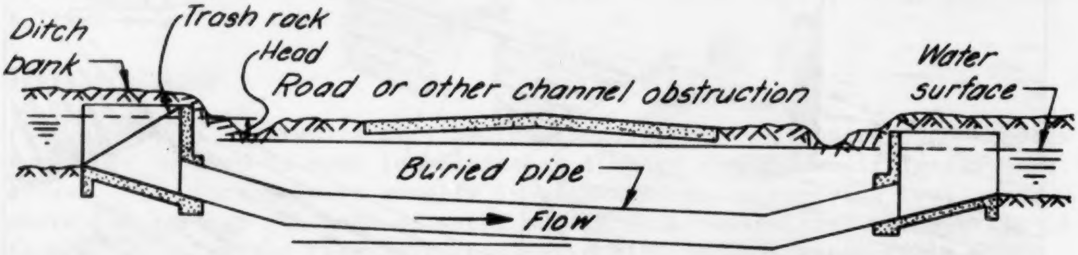


Figure 6-48 Cross section of an inverted siphon

Ditch Crossings

Ditch crossing structures for farm roads frequently are necessary for access to the fields. Culverts are most often used for this purpose. Corrugated metal, smooth metal or concrete are most commonly used for culverts. Inverted siphons are adapted for crossings where the water surface in the ditch is at a higher elevation than the road. Bridges are more often used on large ditches. They can be built so there is little or no head loss through the structure.

EROSION CONTROL STRUCTURES

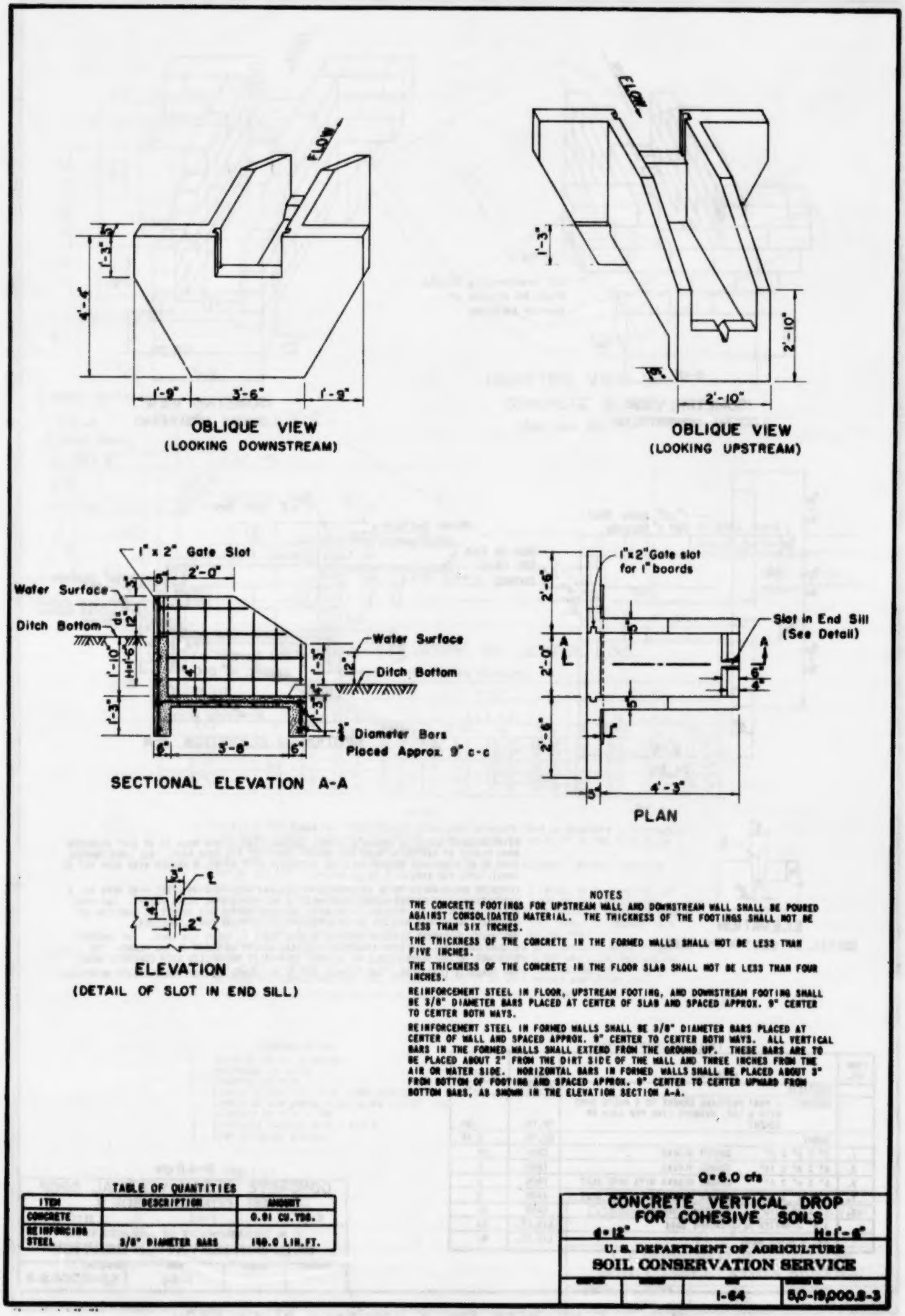
Irrigation ditches are sometimes located where the ditch will have sufficient grade to produce erosive velocities. The eroded material will be deposited downstream, thereby reducing the ditch capacity. Drops, chutes, and pipelines are used to prevent such damages.

Drop Structures

The drop structure is used to control the ditch velocity by lowering the water abruptly from one level to another. This may be accomplished by using a drop spillway or a pipe drop structure. Figure 6-49 is an example of a standard plan for a concrete drop and Figure 6-50 shows a concrete block drop. Figure 6-51 is an example of a corrugated metal pipe drop.

Chutes

Chutes are paved or lined high-velocity open channels. They are adapted to short ditch sections on steep slopes or where drop structures would be so close together that a paved or lined ditch would be more practical. The paving or lining material for the chute must be able to withstand the high velocities. Chutes are most often constructed of concrete. They are complex in design and require the assistance of an engineer. A combination of a drop and chute, Figure 6-52, can sometimes be used where


FLOW
5"
1'-3"
4'-4"
1'-9"
3'-6"
1'-9"
OBLIQUE VIEW
(LOOKING DOWNSTREAM)
FLOW
1'-3"
2'-10"
9"
2'-10"
OBLIQUE VIEW
(LOOKING UPSTREAM)
1" x 2" Gate Slot
2'-0"
5"
Water Surface
Ditch Bottom
d=12"
H=1'-6"
1'-10"
1'-3"
4"
Water Surface
12"
1'-3"
Ditch Bottom
1'-3"
3/8" Diameter Bars
Placed Approx. 9" c-c
6"
3'-8"
6"
SECTIONAL ELEVATION A-A
1"x2" Gate slot
for 1" boards
2'-6"
2'-0"
2'-6"
Slot in End Sill
(See Detail)
A
A
5"
5"
6"
4"
5"
4'-3"
PLAN
3"
℄
4"
2"
ELEVATION
(DETAIL OF SLOT IN END SILL)

NOTES

THE CONCRETE FOOTINGS FOR UPSTREAM WALL AND DOWNSTREAM WALL SHALL BE POURED AGAINST CONSOLIDATED MATERIAL. THE THICKNESS OF THE FOOTINGS SHALL NOT BE LESS THAN SIX INCHES.

THE THICKNESS OF THE CONCRETE IN THE FORMED WALLS SHALL NOT BE LESS THAN FIVE INCHES.

THE THICKNESS OF THE CONCRETE IN THE FLOOR SLAB SHALL NOT BE LESS THAN FOUR INCHES.

REINFORCEMENT STEEL IN FLOOR, UPSTREAM FOOTING, AND DOWNSTREAM FOOTING SHALL BE 3/8" DIAMETER BARS PLACED AT CENTER OF SLAB AND SPACED APPROX. 9" CENTER TO CENTER BOTH WAYS.

REINFORCEMENT STEEL IN FORMED WALLS SHALL BE 3/8" DIAMETER BARS PLACED AT CENTER OF WALL AND SPACED APPROX. 9" CENTER TO CENTER BOTH WAYS. ALL VERTICAL BARS IN THE FORMED WALLS SHALL EXTEND FROM THE GROUND UP. THESE BARS ARE TO BE PLACED ABOUT 2" FROM THE DIRT SIDE OF THE WALL AND THREE INCHES FROM THE AIR OR WATER SIDE. HORIZONTAL BARS IN FORMED WALLS SHALL BE PLACED ABOUT 3" FROM BOTTOM OF FOOTING AND SPACED APPROX. 9" CENTER TO CENTER UPWARD FROM BOTTOM BARS, AS SHOWN IN THE ELEVATION SECTION A-A.

TABLE OF QUANTITIES

ITEM	DESCRIPTION	AMOUNT
CONCRETE		0.91 CU.YDS.
REINFORCING STEEL	3/8" DIAMETER BARS	160.0 LIN.FT.

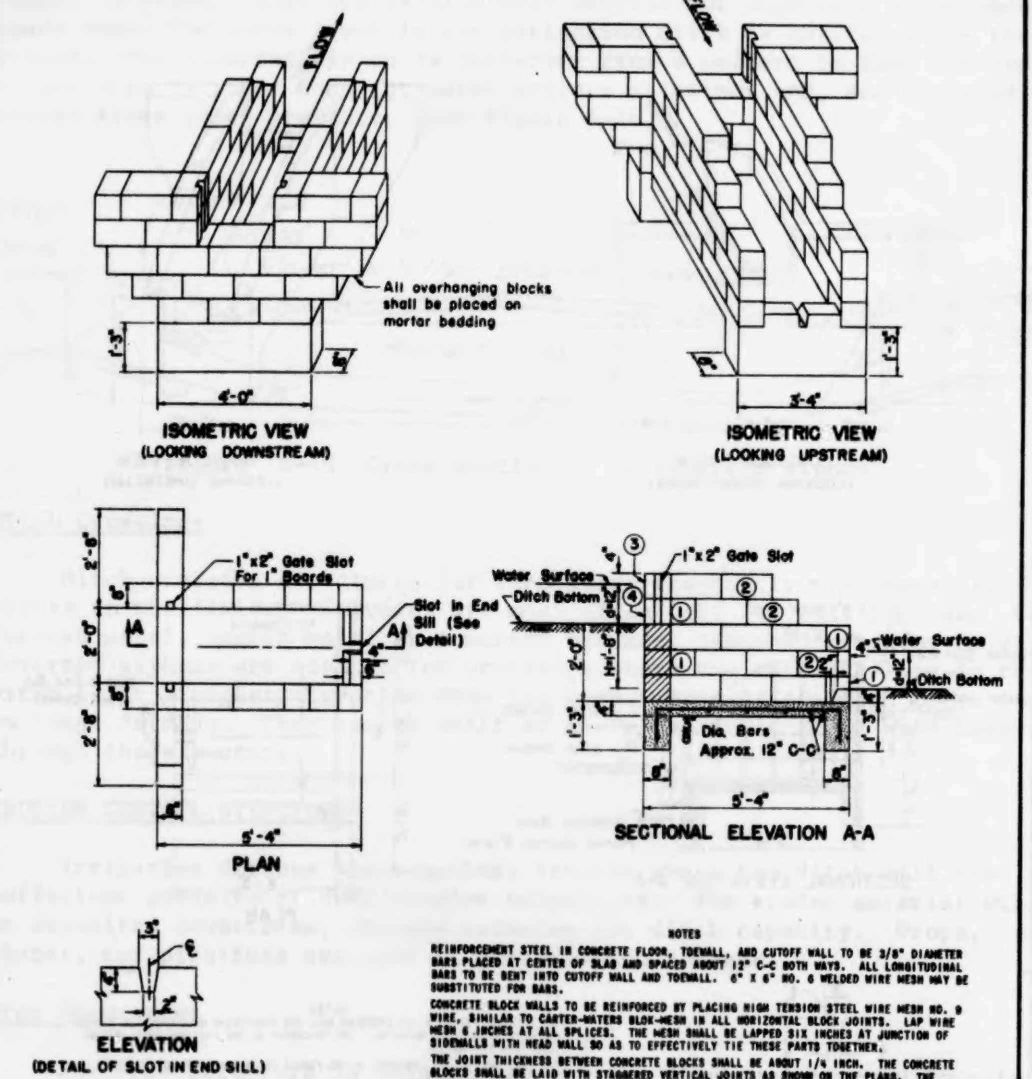
Q = 6.0 cfs

CONCRETE VERTICAL DROP
FOR COHESIVE SOILS
d = 12" H = 1'-6"

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

		1-64	5,0-19,000.8-3

Figure 6-49 Plan for a concrete drop


FLOW
All overhanging blocks shall be placed on mortar bedding
1'-3"
4'-0"
ISOMETRIC VIEW
(LOOKING DOWNSTREAM)
FLOW
1'-3"
5'-4"
ISOMETRIC VIEW
(LOOKING UPSTREAM)
2'-8"
2'-0"
2'-8"
1"x2" Gate Slot For 1" Boards
A
A
Slot in End Sill (See Detail)
4"
6"
8"
5'-4"
PLAN
3
1"x2" Gate Slot
Water Surface
Ditch Bottom
4
2
1
2
1
1
2
1
4"
d=12"
2'-0"
H=1'-8"
1'-3"
Water Surface
Ditch Bottom
1'-3"
Dia. Bars Approx. 12" C-C
6"
6"
5'-4"
SECTIONAL ELEVATION A-A
3"
2"
ELEVATION
(DETAIL OF SLOT IN END SILL)

NOTES

REINFORCEMENT STEEL IN CONCRETE FLOOR, TOEWALL, AND CUTOFF WALL TO BE 3/8" DIAMETER BARS PLACED AT CENTER OF SLAB AND SPACED ABOUT 12" C-C BOTH WAYS. ALL LONGITUDINAL BARS TO BE BENT INTO CUTOFF WALL AND TOEWALL. 6" X 6" NO. 6 WELDED WIRE MESH MAY BE SUBSTITUTED FOR BARS.

CONCRETE BLOCK WALLS TO BE REINFORCED BY PLACING HIGH TENSION STEEL WIRE MESH NO. 9 WIRE, SIMILAR TO CARTER-WATERS BLOK-MESH IN ALL HORIZONTAL BLOCK JOINTS. LAP WIRE MESH 6 INCHES AT ALL SPLICES. THE MESH SHALL BE LAPPED SIX INCHES AT JUNCTION OF SIDEWALLS WITH HEAD WALL SO AS TO EFFECTIVELY TIE THESE PARTS TOGETHER.

THE JOINT THICKNESS BETWEEN CONCRETE BLOCKS SHALL BE ABOUT 1/4 INCH. THE CONCRETE BLOCKS SHALL BE LAID WITH STAGGERED VERTICAL JOINTS AS SHOWN ON THE PLANS. THE OPENINGS IN THE BLOCKS SHALL BE ALIGNED VERTICALLY AND FILLED WITH CONCRETE GROUT.

THE CONCRETE CUTOFF WALL AND TOEWALL ARE TO BE POURED AGAINST CONSOLIDATED MATERIAL.

TABLE OF QUANTITIES

ITEM NO.	MATERIAL	UNIT	QUANTITY
	CONCRETE	CU.YD.	0.40
	MORTAR - 1 PART PORTLAND CEMENT TO 3 PARTS SAND WITH 5 LBS. HYDRATE LIME PER SACK OF CEMENT	CU.YD.	.04
	GROUT	CU.YD.	0.48
1.	8" X 8" X 8" CORNER BLOCKS	EACH	10
2.	8" X 8" X 16" CORNER BLOCKS	EACH	6
3.	8" X 8" X 8" CORNER BLOCKS WITH GATE SLOT	EACH	2
4.	8" X 8" X 16" CORNER BLOCKS WITH GATE SLOT	EACH	2
5.	8" X 8" X 16" STRETCHER BLOCKS	EACH	26
	3/8" DIAMETER REINFORCING BARS	LIN.FT.	53
	NO. 9 BLOCK MESH	LIN.FT.	41

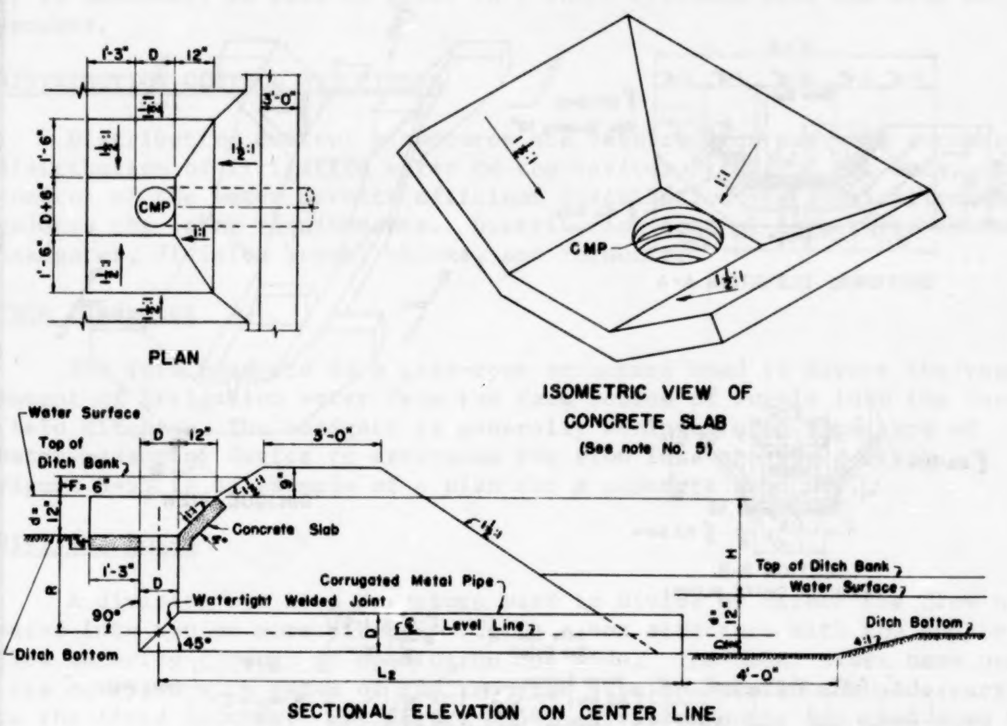
Q=6.0 cfs

CONCRETE BLOCK VERTICAL DROP
FOR COHESIVE SOILS
d=12"
H=1'-8"

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

1-64
5,0-19,000.9-2

Figure 6-50 Plan for a concrete block drop


1'-3"
D
12"
3'-0"
1'-6"
D+6"
1'-6"
$1\frac{1}{2}$:1
1:1
CMP
PLAN
ISOMETRIC VIEW OF
CONCRETE SLAB
(See note No. 5)
Water Surface
Top of
Ditch Bank
F = 6"
d = 12"
Concrete Slab
R
90°
45°
Watertight Welded Joint
Corrugated Metal Pipe
℄ Level Line
Ditch Bottom
L2
H
Top of Ditch Bank
Water Surface
Ditch Bottom
4:1
4'-0"
SECTIONAL ELEVATION ON CENTER LINE

CAPACITY AND LENGTHS REQUIRED

PIPE SIZE	D = 10"				D = 12"				D = 15"			
RECOMMENDED DESIGN CAPACITY	1.6 C.F.S.				2.4 C.F.S.				3.7 C.F.S.			
H = R	V	Q MAX.	L_2	$R+L_2$	V	Q MAX.	L_2	$R+L_2$	V	Q MAX.	L_2	$R+L_2$
1'-0"	4.2	2.3	11'-0"	12'-0"	4.3	3.4	11'-0"	12'-0"	4.5	5.5	11'-0"	12'-0"
1'-6"	5.1	2.8	12'-6"	14'-0"	5.2	4.1	12'-6"	14'-0"	5.4	6.6	12'-6"	14'-0"
2'-0"	5.9	3.2	14'-0"	16'-0"	6.0	4.7	14'-0"	16'-0"	6.1	7.5	14'-0"	16'-0"
2'-6"	6.4	3.5	13'-6"	16'-0"	6.6	5.2	13'-6"	16'-0"	6.6	8.1	13'-6"	16'-0"
3'-0"	6.8	3.7	15'-0"	18'-0"	6.6	5.2	15'-0"	18'-0"	6.6	8.1	15'-0"	18'-0"

NOTES

1. SELECT A PIPE SIZE THAT WILL PROVIDE A GREATER CAPACITY THAN IS REQUIRED TO DISCHARGE THE NORMAL STREAM USED WHEN IRRIGATING. TRY TO KEEP THE VELOCITY IN THE PIPE BELOW 3 FPS BASED ON NORMAL IRRIGATING STREAM.
2. WHEN THE CORRUGATED METAL PIPE DROP IS USED AT A DITCH CROSSING, INCREASE WIDTH OF TOP OF DAM AND DIMENSION L_2 BY 6'-0".
3. THE DROP (H) FOR ANY SPECIFIC STRUCTURE CAN BE INCREASED 3 INCHES BY PLACING THE TOP OF THE RISER PIPE 3 INCHES BELOW THE TOP OF THE CONCRETE FLOOR OF THE INLET. THE THICKNESS OF THE FLOOR SLAB ADJACENT TO THE PIPE SHOULD BE INCREASED 3 INCHES TO MAKE A WATERTIGHT CONNECTION WITH THE PIPE. THE INLET TO THE PIPE SHOULD BE ROUNDED TO A 3 INCH RADIUS TO SAVE FORMING AND IMPROVE THE EFFICIENCY OF THE INLET.
4. THE DROP STRUCTURE IS FORMED BY CUTTING A STANDARD LENGTH OF CORRUGATED METAL PIPE, WHICH IS MANUFACTURED IN MULTIPLES OF 2 FT. IN LENGTH, ON A 45° ANGLE AND WELDING THE CUT JOINTS TOGETHER TO FORM A 90° BEND. PIPE TO BE 16 GA. CORRUGATED METAL. JOINT BETWEEN HORIZONTAL AND VERTICAL PIECES OF PIPE TO BE BUTT WELDED AND WATERTIGHT.
5. SIX INCH HAND PLACED RIP-RAP MAY BE SUBSTITUTED FOR CONCRETE SLAB.

NOMENCLATURE

d - DEPTH OF WATER IN DITCH
F - FREEBOARD IN DITCH
D - DIAMETER OF PIPE
R - LENGTH OF VERTICAL PIPE ALONG CENTER LINE
L_2 - LENGTH OF HORIZONTAL PIPE ALONG CENTER LINE
V - VELOCITY OF PIPE - FPS
Q - DISCHARGE THROUGH PIPE - C.F.S.
H - DROP OF WATER SURFACE

TABLE OF
CONCRETE QUANTITIES

D = 10"	0.25 CU. YDS.
D = 12"	0.26 CU. YDS.
D = 15"	0.29 CU. YDS.

CORRUGATED METAL PIPE DROP
d = 12"
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
1-64
5,0-19,000.11-1

Figure 6-51 Plan for a corrugated metal pipe drop

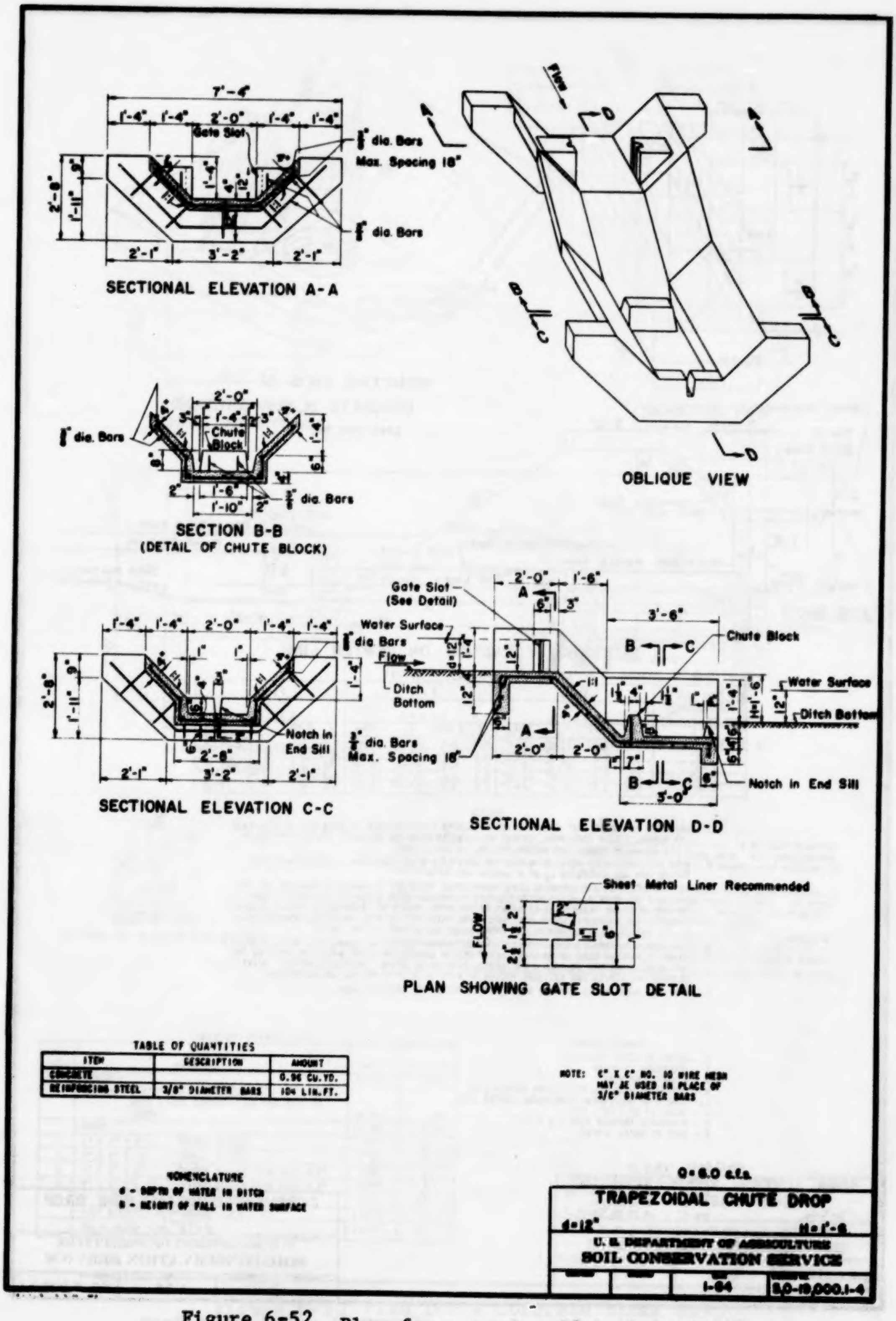

7'-4"
1'-4" 1'-4" 2'-0" 1'-4" 1'-4"
Gate Slot
3/8" dia. Bars Max. Spacing 18"
3/8" dia. Bars
2'-8"
1'-11"
2'-1" 3'-2" 2'-1"
SECTIONAL ELEVATION A-A
Flow
A
D
B
C
OBLIQUE VIEW
2'-0"
1'-4"
Chute Block
3/8" dia. Bars
1'-6"
1'-10"
SECTION B-B
(DETAIL OF CHUTE BLOCK)
1'-4" 1'-4" 2'-0" 1'-4" 1'-4"
3/8" dia. Bars
2'-8"
1'-11"
Notch in End Sill
2'-8"
2'-1" 3'-2" 2'-1"
SECTIONAL ELEVATION C-C
Gate Slot (See Detail)
2'-0" 1'-6"
3'-6"
Water Surface
Flow
Ditch Bottom
d=12"
1:1
Chute Block
Water Surface
Ditch Bottom
H=1'-6"
3/8" dia. Bars Max. Spacing 18"
2'-0" 2'-0"
7"
3'-0"
Notch in End Sill
SECTIONAL ELEVATION D-D
Sheet Metal Liner Recommended
FLOW
PLAN SHOWING GATE SLOT DETAIL
NOMENCLATURE
d - DEPTH OF WATER IN DITCH
H - HEIGHT OF FALL IN WATER SURFACE
Q = 6.0 c.f.s.
TRAPEZOIDAL CHUTE DROP
d=12"
H=1'-6
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
1-64
5,0-19,000.1-4

TABLE OF QUANTITIES

ITEM	DESCRIPTION	AMOUNT
CONCRETE		0.96 CU. YD.
REINFORCING STEEL	3/8" DIAMETER BARS	104 LIN. FT.

NOTE: 6" X 6" NO. 10 WIRE MESH MAY BE USED IN PLACE OF 3/8" DIAMETER BARS

Figure 6-52 Plan for a trapezoidal chute drop

it is necessary to take up grade in a short distance like the drop between benches.

DISTRIBUTION CONTROL STRUCTURES

Distribution control structures are required for easy and accurate distribution of irrigation water to the various fields on the farm. Good control of the water permits efficient distribution and application and reduces the labor requirements. Distribution control structures include headgates, division boxes, checks, and turnouts.

Farm Headgates

The farm headgate is a gate-type structure used to divert the required amount of irrigation water from the farm source of supply into the farm field ditches. The headgate is generally equipped with some type of water-measuring device to determine the flow into the field ditch. Figure 6-53 is an example of a plan for a concrete headgate.

Division Boxes

A division box is a structure used to divide or direct the flow of water into two or more ditches. It is a box structure with the supply flow entering through an opening on one side. The other sides have openings equipped with gates of the required size to furnish the necessary flow to the field ditches. See Figure 6-54. Division boxes are used also with pump installations to control the flow from the pump into one of two or more field ditches. Figure 6-55 shows a combination pump outlet and division box.

Checks

A check is a structure placed in a ditch to control the elevation of the water surface above the structure. The water level is raised as necessary so that it can be diverted from the ditch. Checks are either portable or permanent. Portable checks are removed after they have served their purpose for irrigating a given area and are reset for irrigating another area. The portable check is available commercially and is generally made of canvas, plastic, rubber, or metal. A permanent check is a headwall with a weir-type opening equipped with stoplogs or slide gates for adjusting the upstream elevation of the water surface. Figure 6-56 is a standard plan for one type of concrete check.

Turnouts

The turnout is a box or orifice-type structure located in the bank of the head ditch for controlling the flow of water from the head ditch into border strips, contour levee areas, and contour ditches. The structure is equipped with a simple slide gate for regulating the flow. Wooden or concrete boxes and concrete or metal pipe are generally used for turnouts. An example of a plan for a concrete turnout is shown in Figure 6-57.

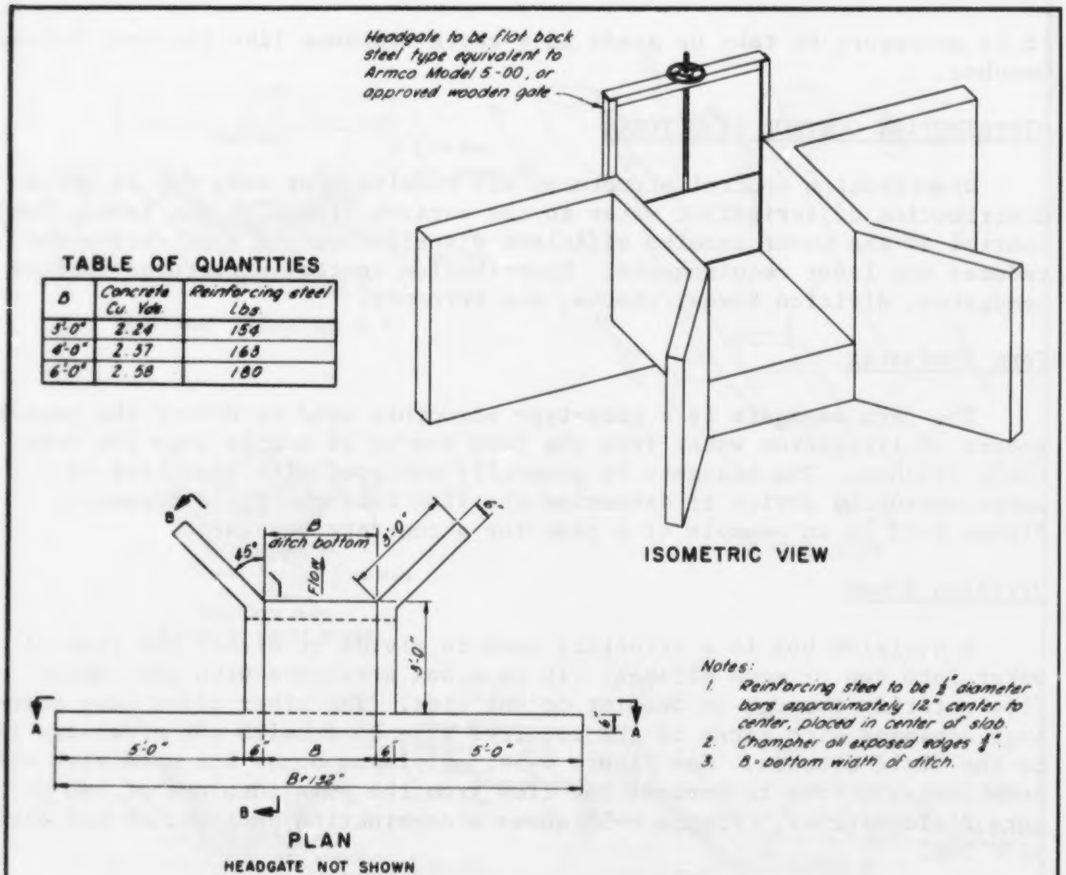

Headgate to be flat back steel type equivalent to Armco Model 5-00, or approved wooden gate
ISOMETRIC VIEW
B
B
ditch bottom
45°
Flow
3'-0"
6"
3'-0"
A
A
6"
5'-0"
6"
B
6"
5'-0"
B+132"
B
PLAN
HEADGATE NOT SHOWN
3'-0"
5'-0"
5'-0"
6"
B
6"
5'-0"
B+132"
ELEVATION A-A
HEADGATE NOT SHOWN
3'-0"
5'-0"
1'-6"
6"
1'-6"
4'-6"
6"
2'-6"
6"
3'-0"
6'-6"
SECTIONAL ELEVATION B-B
HEADGATE NOT SHOWN

TABLE OF QUANTITIES

B	Concrete Cu. Yds.	Reinforcing steel Lbs.
3'-0"	2.24	154
4'-0"	2.37	163
6'-0"	2.58	180

Notes:
1. Reinforcing steel to be ⅜" diameter bars approximately 12" center to center, placed in center of slab.
2. Chamfer all exposed edges ¾".
3. B = bottom width of ditch.

CONCRETE HEADGATE STRUCTURE
B = 3'-0", 4'-0", 6'-0"
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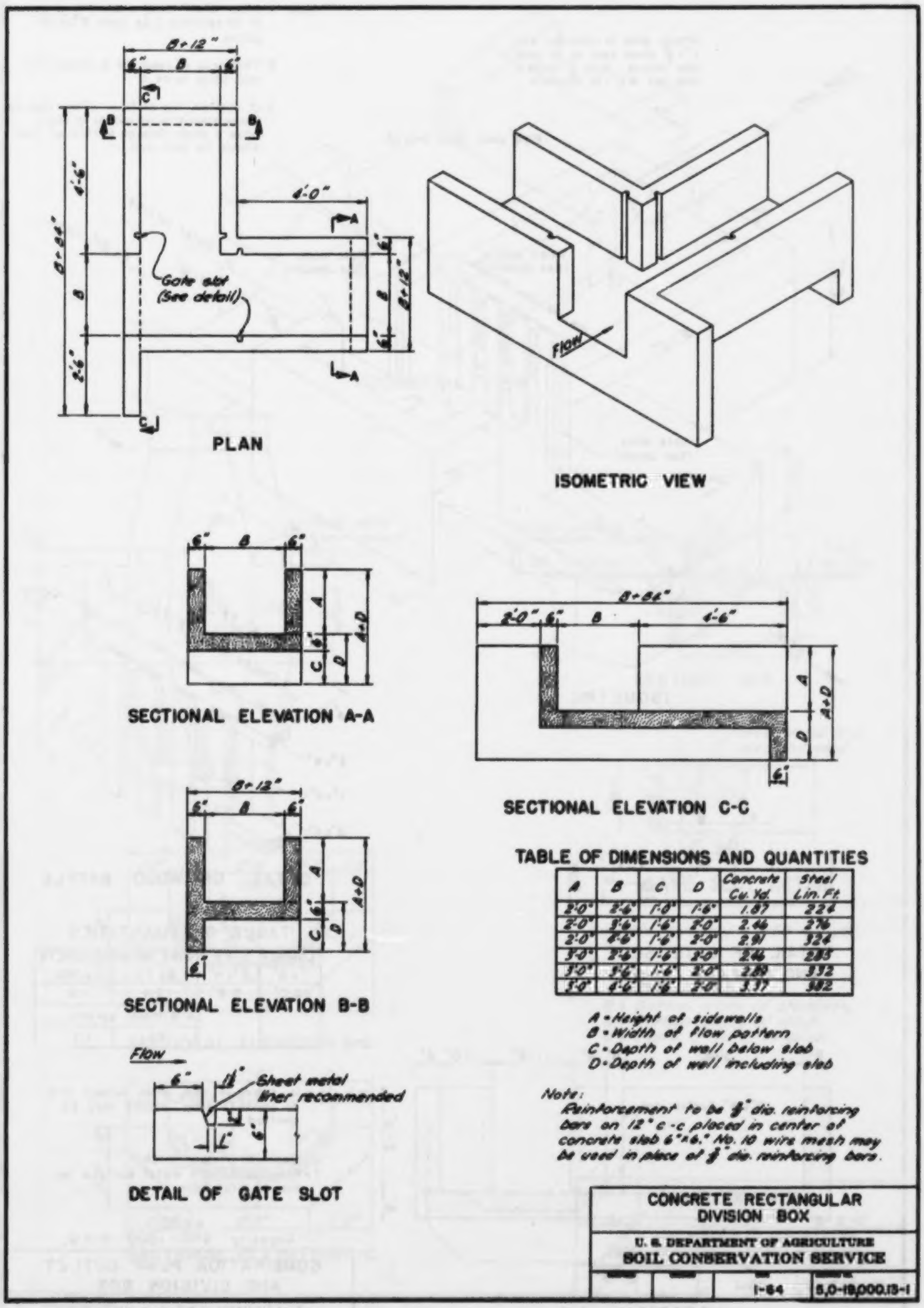
5,0-19,000.34-1

Figure 6-53 Plan for a concrete headgate


B+12"
6"
B
6"
C
B
B
4'-6"
4'-0"
A
B+24"
B
Gate slot
(See detail)
6"
B
6"
B+12"
2'-6"
A
C
Flow
6"
B
6"
A
A+D
6"
C
D
B+24"
2'-0"
6"
B
4'-6"
A
A+D
D
6"
B+12"
6"
B
6"
A
A+D
6"
C
D
6"
Flow
6"
1½"
Sheet metal
liner recommended
1"
6"

PLAN

ISOMETRIC VIEW

SECTIONAL ELEVATION A-A

SECTIONAL ELEVATION C-C

SECTIONAL ELEVATION B-B

DETAIL OF GATE SLOT

TABLE OF DIMENSIONS AND QUANTITIES

A	B	C	D	Concrete Cu. Yd.	Steel Lin. Ft.
2'-0"	2'-6"	1'-0"	1'-6"	1.87	224
2'-0"	3'-6"	1'-6"	2'-0"	2.46	276
2'-0"	4'-6"	1'-6"	2'-0"	2.91	324
3'-0"	2'-6"	1'-6"	2'-0"	2.46	285
3'-0"	3'-6"	1'-6"	2'-0"	2.89	332
3'-0"	4'-6"	1'-6"	2'-0"	3.37	382

A = Height of sidewalls
B = Width of flow pattern
C = Depth of wall below slab
D = Depth of wall including slab

Note:
Reinforcement to be ⅜" dia. reinforcing bars on 12" c-c placed in center of concrete slab 6"×6." No. 10 wire mesh may be used in place of ⅜" dia. reinforcing bars.

CONCRETE RECTANGULAR
DIVISION BOX

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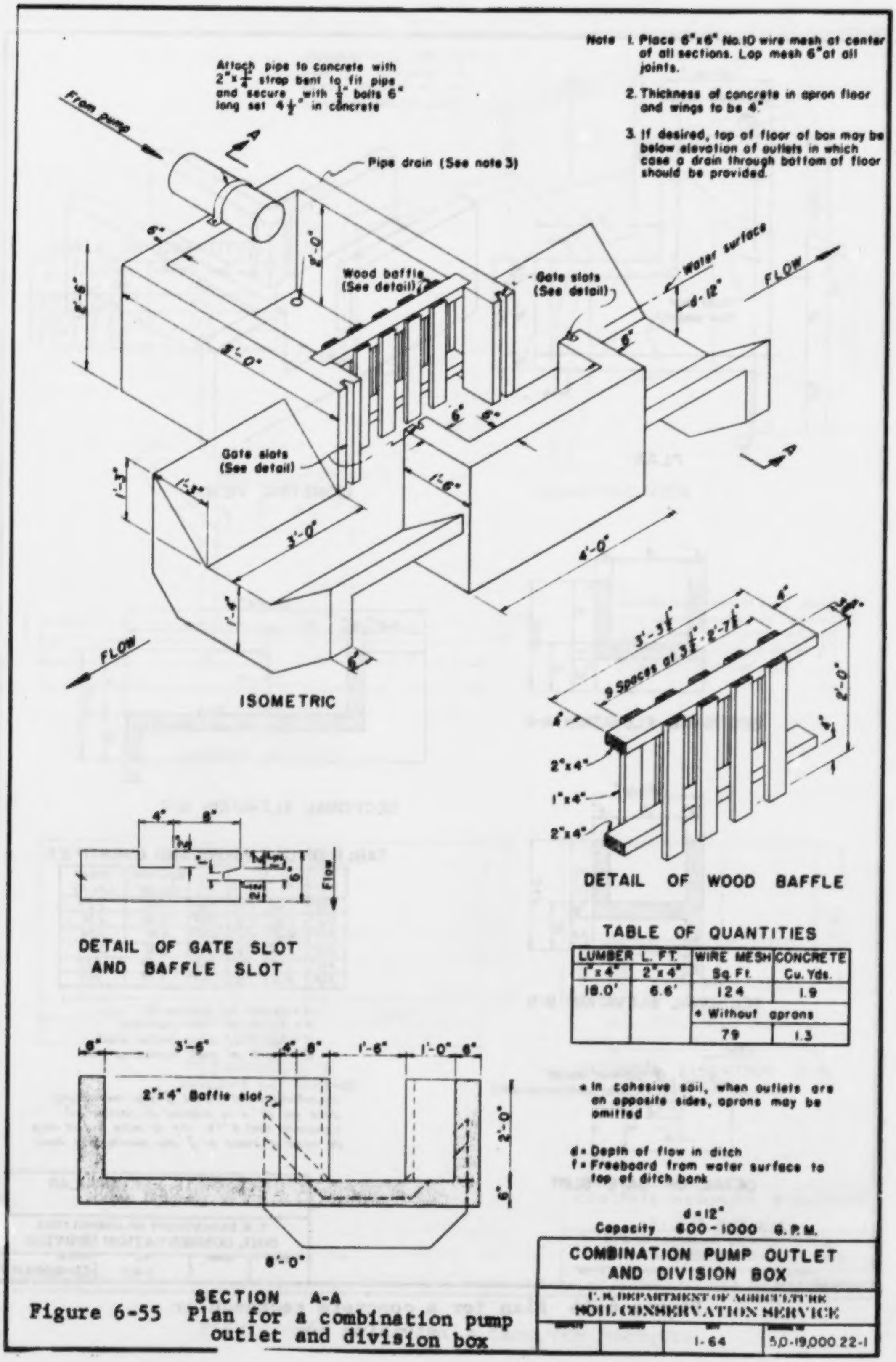
Figure 6-54 Plan for a concrete rectangular division box


Attach pipe to concrete with 2"x¼" strap bent to fit pipe and secure with ½" bolts 6" long set 4½" in concrete
From pump
A
Pipe drain (See note 3)
6"
2'-6"
2'-0"
8'-0"
Wood baffle (See detail)
Gate slots (See detail)
Water surface
d-12"
FLOW
6"
6"
6"
Gate slots (See detail)
1'-3"
1'-3"
1'-6"
3'-0"
4'-0"
1'-4"
6"
FLOW
A
3'-3½"
6"
9 Spaces at 3½"-2'-7½"
2'-0"
4"
4"
2"x4"
1"x4"
2"x4"
4"
8"
Flow
6"
3'-6"
4"
8"
1'-6"
1'-0"
6"
2"x4" Baffle slot
2'-0"
6"
8'-0"

ISOMETRIC

DETAIL OF WOOD BAFFLE

DETAIL OF GATE SLOT AND BAFFLE SLOT

SECTION A-A

Note
1. Place 6"x6" No.10 wire mesh at center of all sections. Lap mesh 6" at all joints.
2. Thickness of concrete in apron floor and wings to be 4"
3. If desired, top of floor of box may be below elevation of outlets in which case a drain through bottom of floor should be provided.

TABLE OF QUANTITIES

LUMBER L. FT.		WIRE MESH	CONCRETE
1"x4"	2"x4"	Sq. Ft.	Cu. Yds.
18.0'	6.6'	124	1.9
		* Without aprons	
		79	1.3

* In cohesive soil, when outlets are on opposite sides, aprons may be omitted

d = Depth of flow in ditch
f = Freeboard from water surface to top of ditch bank

d = 12"
Capacity 600 - 1000 G.P.M.

COMBINATION PUMP OUTLET AND DIVISION BOX

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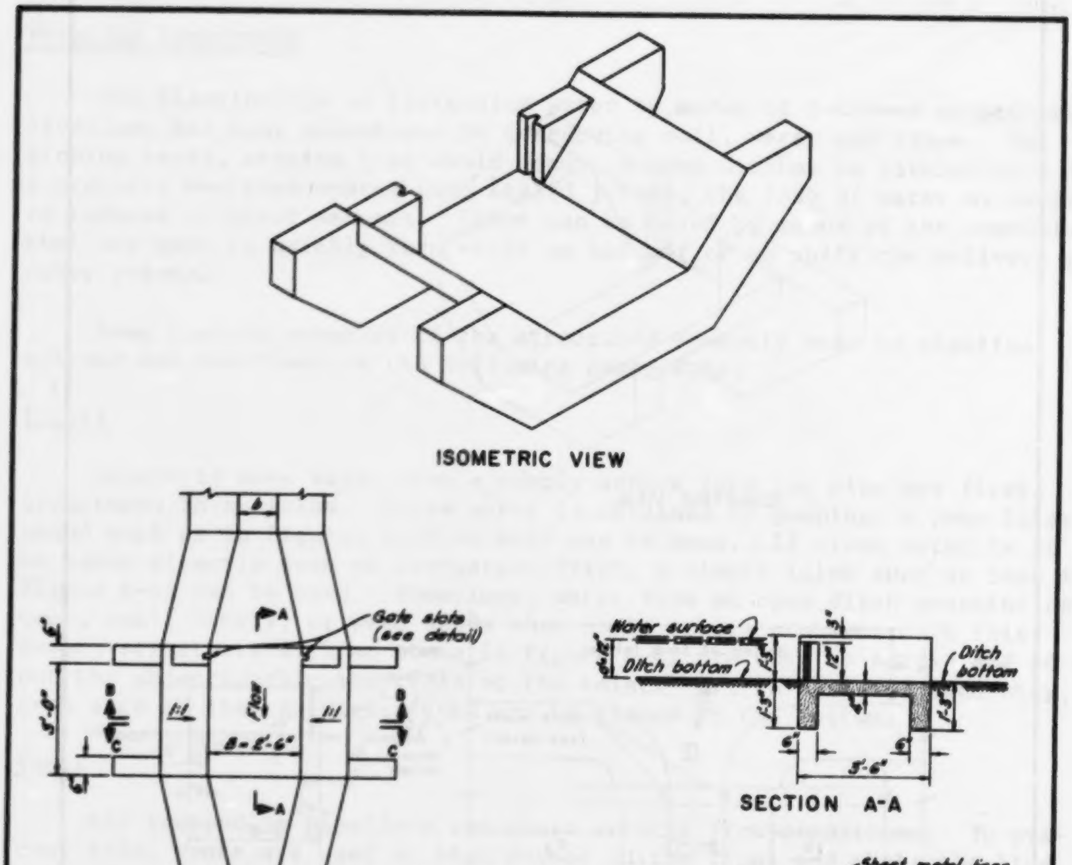
Figure 6-55 Plan for a combination pump outlet and division box


ISOMETRIC VIEW
PLAN
b
Gate slots
(see detail)
A
B
C
Flow
1:1
B = 2'-6"
5'-0"
6"
SECTION A-A
Water surface
Ditch bottom
1'-3"
3"
1'-0"
6"
5'-6"
GATE SLOT DETAIL
Sheet metal liner recommended
Flow
2"
1"
6"
Concrete quantity = 0.60 cu. yd.
NOMENCLATURE
B = Bottom width of structure
b = Bottom width of ditch
d = Depth of water in ditch
SECTIONAL ELEVATION B-B
7'-6"
1'-5"
1'-3"
2'-6"
1'-5"
1'-5"
Water surface
1:1
1:1
1'-11"
5'-6"
1'-11"
SECTIONAL ELEVATION C-C
7'-6"
2'-6"
CONCRETE CHECK
d = 12"
B = 2'-6"
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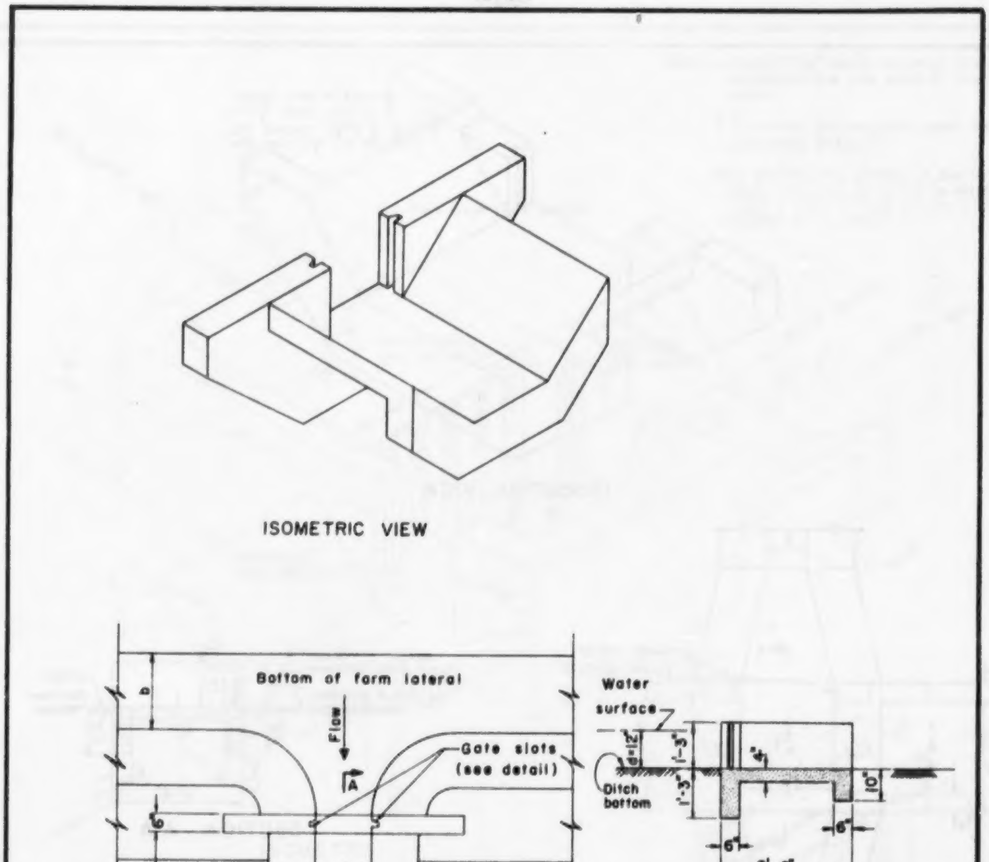
SO-10000-B-1

Figure 6-56 Plan for a concrete check


ISOMETRIC VIEW
Bottom of farm lateral
b
Flow
Gate slots
(see detail)
A
6"
3'-0"
B
C
1:1
B=1'-6"
1:1
B
C
A
PLAN
Water
surface
d=12"
1'-3"
4"
10"
Ditch
bottom
1'-3"
6"
6"
3'-6"
SECTION A-A
Sheet metal liner
recommended
Flow
2"
1/2"
2"
2"
1/2"
2"
6"
DETAIL OF GATE SLOT
1'-3"
1'-3"
1'-6"
1'-3"
1'-3"
9"
1'-9"
1:1
1'-3"
1:1
11"
1'-7"
2'-6"
1'-7"
SECTIONAL ELEVATION B-B
1'-3"
1'-6"
1'-3"
1'-2"
1:1
1'-3"
1:1
11"
6"
6"
6"
11"
2'-2"
11"
SECTIONAL ELEVATION C-C
Concrete quantity = 0.44 cu. yd.
NOMENCLATURE
B = Bottom width of structure
b = Bottom width of ditch
d = Depth of water in ditch
CONCRETE TURNOUT
d = 12"
B = 1'-6"
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5,0-19,000.17-1

Figure 6-57 Plan for a concrete turnout

PIPELINE STRUCTURES

The distribution of irrigation water by means of low-head underground pipelines has many advantages in conserving soil, water and labor. On sloping lands, erosion that could occur in open ditches is eliminated. In a properly designed system with sealed joints, the loss of water by seepage is reduced to minor amounts. Labor can be saved by means of the controls that are used to quickly turn water on and off or to shift the delivery to other points.

Some typical examples of the structures commonly used in pipeline systems are described in the following paragraphs.

Inlets

Inlets to move water from a supply source into the pipe are first structures in a system. Where water is obtained by pumping, a pump inlet stand such as in Figures 6-58 or 6-59 may be used. If clean water is to be taken directly from an irrigation ditch, a simple inlet such as that in Figure 6-60 can be used. Sometimes, water from an open ditch contains sediment, small debris, or weed seeds that could create problems. In this event, structures such as those in Figure 6-61 are used to settle and screen out the objectionable materials at the inlet. Or, in cases of sand only, a trap such as that in Figure 6-62 may be placed in the system.

Vents

Air trapped in pipelines can cause erratic flow conditions. To prevent this, vents are used at high points in the lines and where the line makes abrupt changes in grade. A simple type of vent is illustrated in Figure 6-63.

Outlets

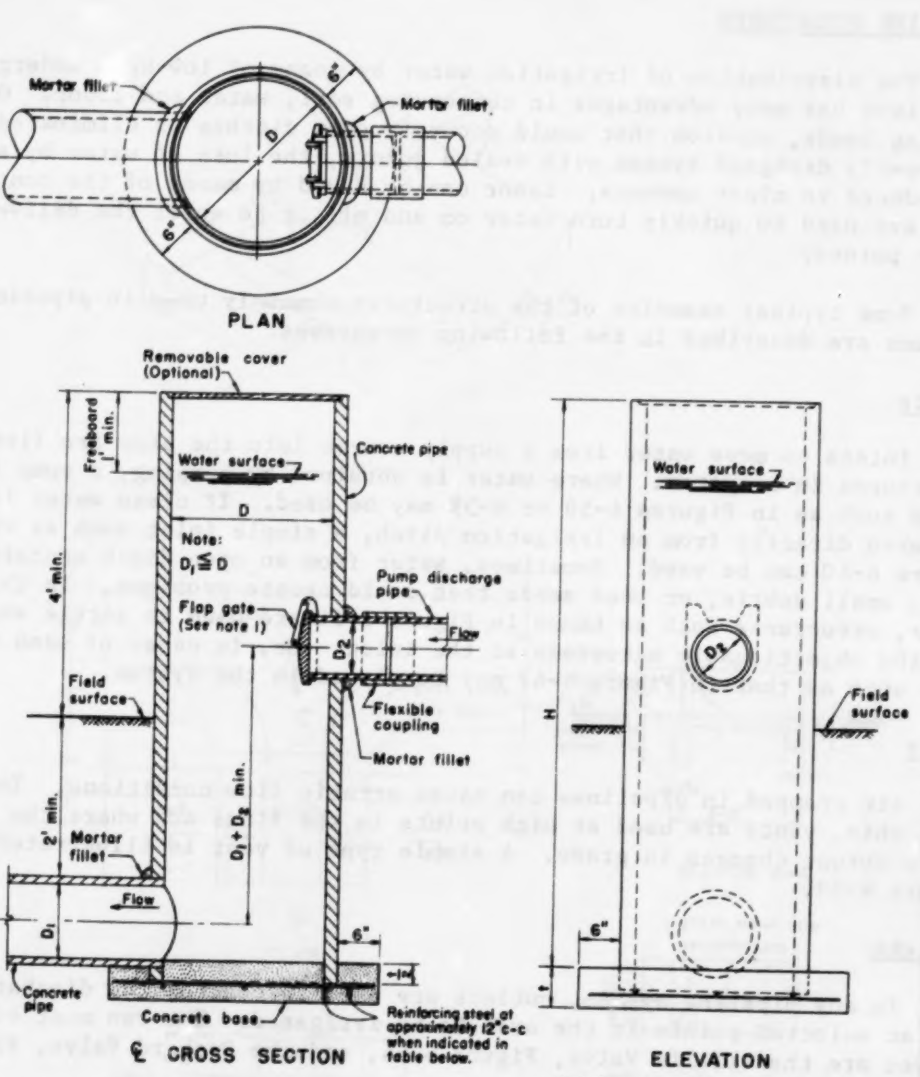
In any pipeline system, outlets are used to control the discharge of water at selected points in the area to be irrigated. The two most common valves are the Alfalfa Valve, Figure 6-64, and the Orchard Valve, Figure 6-65.

Further discussion and examples of pipeline structures can be found in Chapter 3, Section 15, N.E.H. Also, locally adopted standard plans may be available.

19. STRUCTURE DESIGN

After information needed for a structure design has been obtained by a field survey, it and other pertinent information should be recorded on a structure data sheet or plan. All recorded information, calculations, and design data should be checked for accuracy.

The detailed structure design develops the overall plan for the structure as indicated on the structure data sheet. Such items as dimensions of the various parts of the structure, spacing of steel reinforcing bars in


Mortar fillet
Mortar fillet
6"
6"
D
PLAN
Removable cover
(Optional)
Freeboard 1' min.
Concrete pipe
Water surface
D
Note:
D₁ ≦ D
Pump discharge pipe
Flap gate
(See note 1)
Flow
D₂
Field surface
Flexible coupling
Mortar fillet
D₁+D₂ min.
4' min.
4' min.
Mortar fillet
Flow
D₁
6"
1in.
Concrete pipe
Concrete base
Reinforcing steel at approximately 12" c-c when indicated in table below.
℄ CROSS SECTION
Water surface
D₂
Field surface
H
6"
t
ELEVATION

Notes:

1. When D ≦ 27" or when D₂ is greater than ½ D eliminate flap gate and use a check valve in pump discharge pipe.

NOMENCLATURE

D - Diameter of vertical pipe

D₁ - Diameter of underground pipe

D₂ - Diameter of pump discharge pipe

t - Thickness of concrete base

H - Height of vertical pipe above top of concrete base

Q - Discharge through structure in cfs. and g.p.m.

Max. Q		D	A.S.T.M. Spec.		Concrete Base					
					H=10' or less		H=more than 10'		Reinforcing steel	
c. f. s.	g.p.m.	Inches	No.	Type	t	Cu.yd.	t	Cu.yd.	Size	Length
0.79	355	12	C-118	Concrete Irrigation Pipe	4"	0.05	6"	0.07	—	—
1.07	480	14			4"	0.05	6"	0.08	—	—
1.23	550	15			4"	0.06	6"	0.09	—	—
1.40	630	16			4"	0.06	6"	0.10	—	—
1.77	795	18			4"	0.07	6"	0.11	—	—
2.18	980	20			6"	0.13	8"	0.17	—	—
2.41	1080	21			6"	0.14	8"	0.18	—	—
3.14	1410	24			6"	0.16	8"	0.22	—	—
3.98	1785	27	C-76	Class II Reinforced Concrete Pipe	6"	0.20	8"	0.26	3/8"	19'
4.91	2205	30			6"	0.23	8"	0.30	3/8"	21'
5.94	2665	33			8"	0.35	8"	0.35	3/8"	22'
7.07	3175	36			8"	0.39	8"	0.39	3/8"	23'
9.62	4320	42			8"	0.50	8"	0.50	3/8"	38'
12.57	5640	48			8"	0.62	8"	0.62	1/2"	46'

Figure 6-58 Plan for high head non-tapered pump stand for concrete pipe

HIGH HEAD NON-TAPERED
PUMP STAND FOR CONCRETE PIPE
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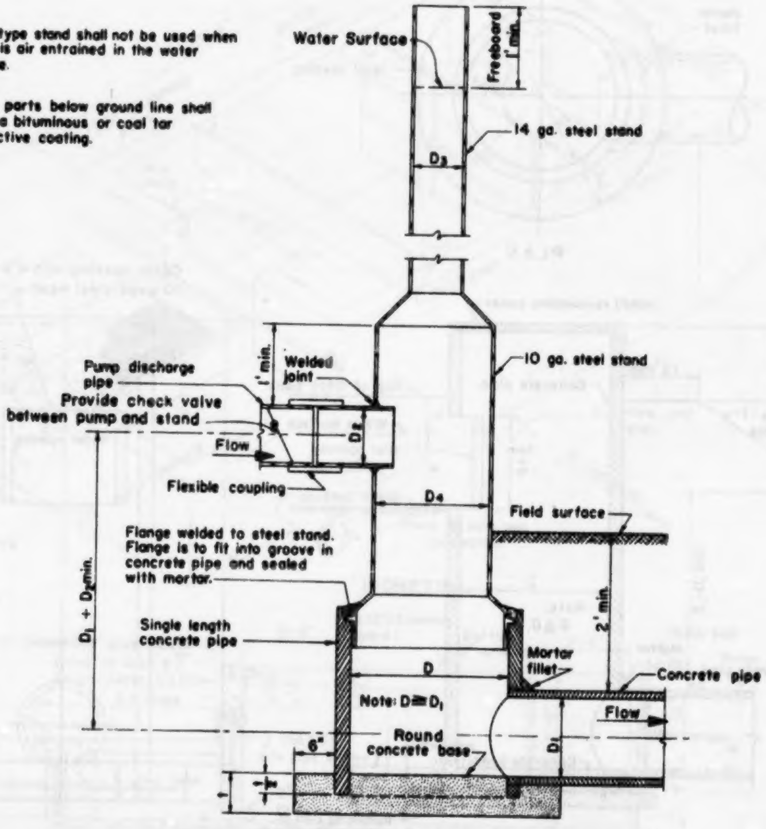
Note: This type stand shall not be used when there is air entrained in the water source.

Metal parts below ground line shall have a bituminous or coal tar protective coating.


Water Surface
Freeboard 1' min.
14 ga. steel stand
D3
10 ga. steel stand
1' min.
Welded joint
Pump discharge pipe
Provide check valve between pump and stand
Flow
D2
Flexible coupling
D4
Field surface
Flange welded to steel stand. Flange is to fit into groove in concrete pipe and sealed with mortar.
D1 + D2 min.
2' min.
Single length concrete pipe
Mortar fillet
D
Concrete pipe
Note: D ≧ D1
Flow
Round concrete base
D1
6"
t

℄ CROSS SECTION

Max. Q		Concrete Pipe			Steel Stand				Concrete Base	
		D	A.S.T.M. Spec.		D4 Min.		D3 Min.		t	Volume
c.f.s.	g.p.m.	Inches	No.	Type	Inches	Gage	Inches	Gage	Inches	Cu. yd.
0.79	355	12	C-118	Concrete Irrigation Pipe	8 1/2	10	3 7/8	14	4	0.05
1.07	480	14	C-118		10	10	4 1/2	14	4	0.05
1.23	550	15	C-118		10 5/8	10	4 3/4	14	4	0.06
1.40	630	16	C-118		11 3/8	10	5 1/8	14	4	0.06
1.77	795	18	C-118		12 3/4	10	5 3/4	14	4	0.07
2.18	980	20	C-118		14 1/4	10	6 3/8	14	6	0.13
2.41	1080	21	C-118		14 7/8	10	6 3/4	14	6	0.14
3.14	1410	24	C-118		17	10	7 5/8	14	6	0.16
3.98	1785	27	C-76	Class II Reinforced Concrete Pipe	19 1/8	10	8 5/8	14	6	0.20
4.91	2205	30	C-76		21 1/4	10	9 1/2	14	6	0.23
5.94	2665	33	C-76		23 3/8	10	10 1/2	14	8	0.35
7.07	3175	36	C-76		25 1/2	10	11 1/2	14	8	0.39
9.62	4320	42	C-76		29 3/4	10	13 3/8	14	8	0.50
12.57	5640	48	C-76		34	10	15 1/4	14	8	0.62

NOMENCLATURE

D – Diameter of vertical concrete pipe

D_1 – Diameter of underground pipe

D_2 – Diameter of pump discharge pipe

D_3 – Diameter of upper steel stand pipe

D_4 – Diameter of lower steel stand pipe

t – Thickness of concrete base

Q – Discharge through structure in c.f.s. and g.p.m.

HIGH HEAD STEEL TAPERED PUMP
STAND FOR CONCRETE PIPE

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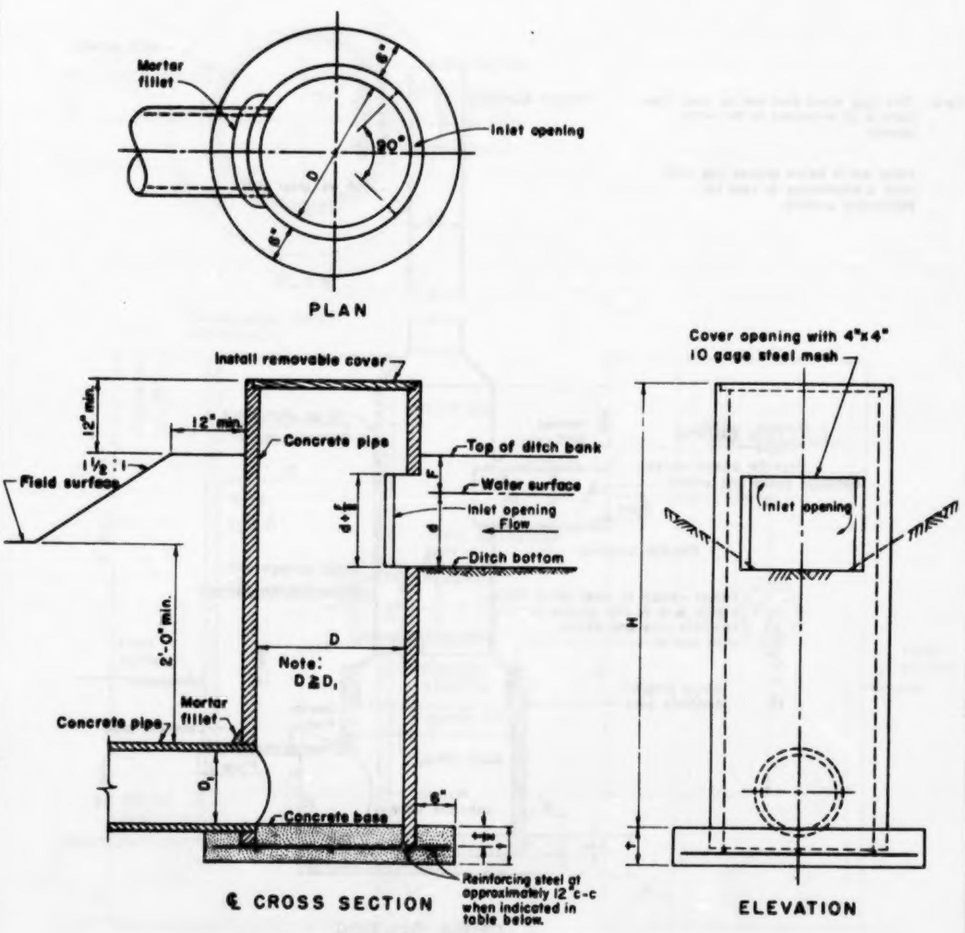
Figure 6-59 Plan for a high head steel tapered pump stand for concrete pipe


Mortar fillet
Inlet opening
90°
6"
D
6"
PLAN
Install removable cover
12" min.
12" min.
1½ : 1
Field surface
Concrete pipe
Top of ditch bank
F
Water surface
d+F
d
Inlet opening
Flow
Ditch bottom
2'-0" min.
D
Note:
D ≧ D₁
Mortar fillet
Concrete pipe
D₁
Concrete base
6"
t
Reinforcing steel at approximately 12" c-c when indicated in table below.
℄ CROSS SECTION
Cover opening with 4"x4" 10 gage steel mesh
Inlet opening
H
t
ELEVATION

Max. Q		D	A.S.T.M. Spec.		Concrete Base					
					H=10' or less		H=more than 10'		Reinforcing steel	
c. f. s.	g.p.m.	Inches	No.	Type	t	Cu.yd.	t	Cu.yd.	Size	Length
0.79	355	12	C-118	Concrete Irrigation Pipe	4"	0.05	6"	0.07	—	—
1.07	480	14			4"	0.05	6"	0.08	—	—
1.23	550	15			4"	0.06	6"	0.09	—	—
1.40	630	16			4"	0.06	6"	0.10	—	—
1.77	795	18			4"	0.07	6"	0.11	—	—
2.18	980	20			6"	0.13	6"	0.17	—	—
2.41	1080	21			6"	0.14	6"	0.18	—	—
3.14	1410	24			6"	0.16	6"	0.22	—	—
3.98	1785	27	C-76	Class II Reinforced Concrete Pipe	6"	0.20	6"	0.26	3/8"	19'
4.91	2205	30			6"	0.23	6"	0.30	3/8"	21'
5.94	2665	33			6"	0.35	6"	0.35	3/8"	22'
7.07	3175	36			6"	0.39	6"	0.39	3/8"	23'
9.62	4320	42			6"	0.50	6"	0.50	3/8"	36'
12.57	5640	48			6"	0.62	6"	0.62	1/2"	46'

NOMENCLATURE

d = Depth of water in ditch
F = Freeboard in ditch
D = Diameter of vertical pipe
D_1 = Diameter of underground pipe
t = Thickness of concrete base
H = Height of vertical pipe above top of concrete base
Q = Discharge through structure in c.f.s. and g.p.m.

GRAVITY INLET
FOR CONCRETE PIPE

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Figure 6-60 Plan for a gravity inlet for concrete pipe

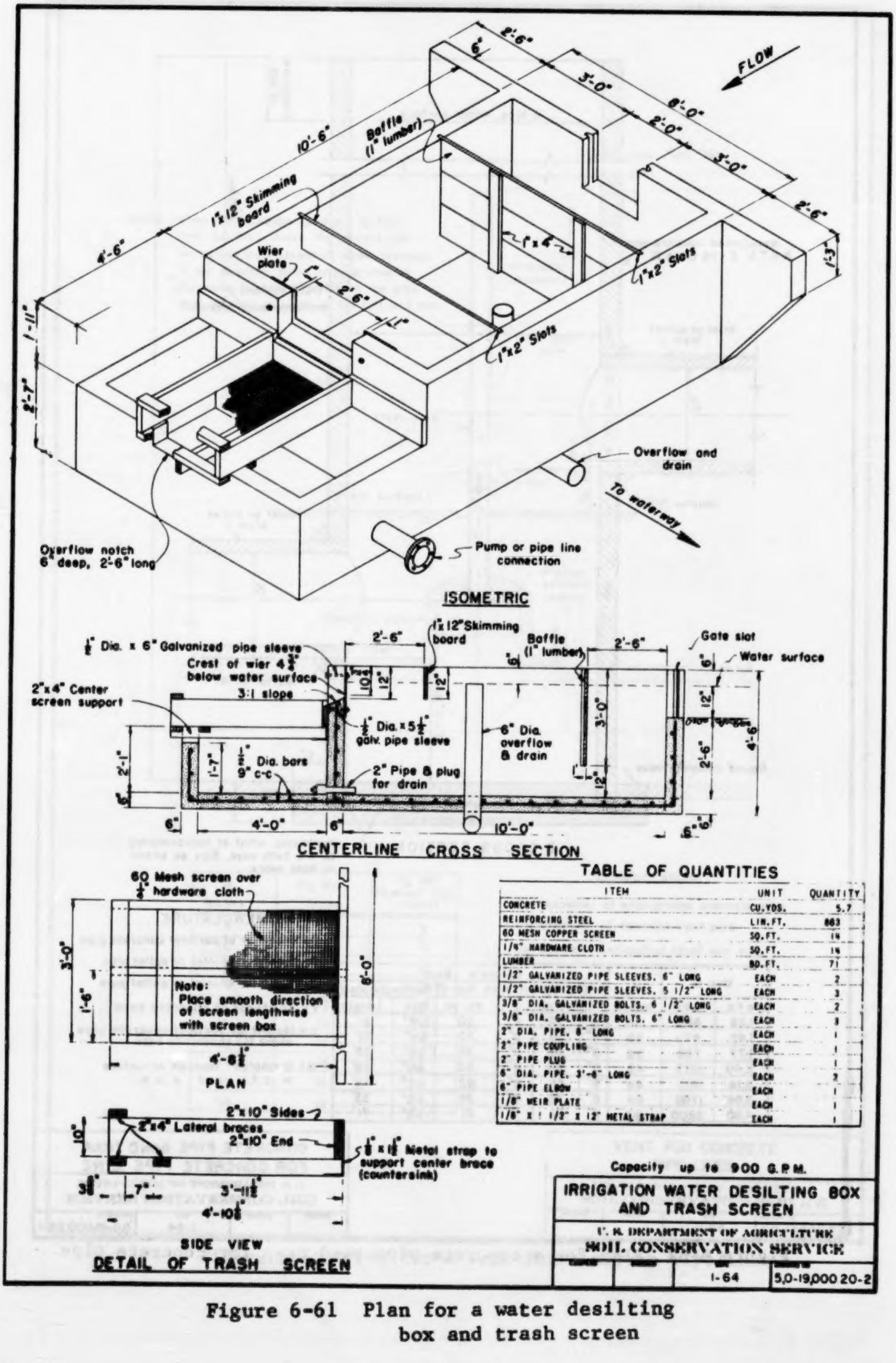
6"
2'-6"
FLOW
3'-0"
8'-0"
2'-0"
3'-0"
2'-6"
1'-3"
Baffle (1" lumber)
10'-6"
1"x12" Skimming board
4'-6"
Wier plate
2'6"
1"
1"x4"
1"x2" Slots
1"x2" Slots
1'-11"
2'-7"
Overflow and drain
To waterway
Pump or pipe line connection
Overflow notch 6" deep, 2'-6" long
ISOMETRIC
1/2" Dia. x 6" Galvanized pipe sleeve
Crest of wier 4 3/4" below water surface
2"x4" Center screen support
3:1 slope
2'-6"
1"x12" Skimming board
10"
12"
12"
Baffle (1" lumber)
6"
2'-6"
Gate slot
Water surface
6"
12"
1/2" Dia. x 5 1/2" galv. pipe sleeve
6" Dia. overflow & drain
3'-0"
2'-6"
4'-6"
12"
2'-1"
1'-7"
1/2" Dia. bars 9" c-c
2" Pipe & plug for drain
6"
6"
4'-0"
6"
10'-0"
6"
6"
CENTERLINE CROSS SECTION
60 Mesh screen over 1/4" hardware cloth
3'-0"
1'-6"
8'-0"
Note: Place smooth direction of screen lengthwise with screen box
4'-8 1/2"
PLAN
2"x10" Sides
2"x4" Lateral braces
2"x10" End
10"
1/8" x 1 1/2" Metal strap to support center brace (countersink)
3 1/2"
7"
3'-11 1/2"
4'-10 3/8"
SIDE VIEW
DETAIL OF TRASH SCREEN

TABLE OF QUANTITIES

ITEM	UNIT	QUANTITY
CONCRETE	CU.YDS.	5.7
REINFORCING STEEL	LIN.FT.	883
60 MESH COPPER SCREEN	SQ.FT.	14
1/4" HARDWARE CLOTH	SQ.FT.	14
LUMBER	BD.FT.	71
1/2" GALVANIZED PIPE SLEEVES, 6" LONG	EACH	2
1/2" GALVANIZED PIPE SLEEVES, 5 1/2" LONG	EACH	3
3/8" DIA. GALVANIZED BOLTS, 6 1/2" LONG	EACH	2
3/8" DIA. GALVANIZED BOLTS, 6" LONG	EACH	3
2" DIA. PIPE, 8" LONG	EACH	1
2" PIPE COUPLING	EACH	1
2" PIPE PLUG	EACH	1
6" DIA. PIPE, 3'-6" LONG	EACH	2
6" PIPE ELBOW	EACH	1
1/8" WEIR PLATE	EACH	1
1/8" X 1 1/2" X 12" METAL STRAP	EACH	1

Capacity up to 900 G.P.M.

IRRIGATION WATER DESILTING BOX
AND TRASH SCREEN

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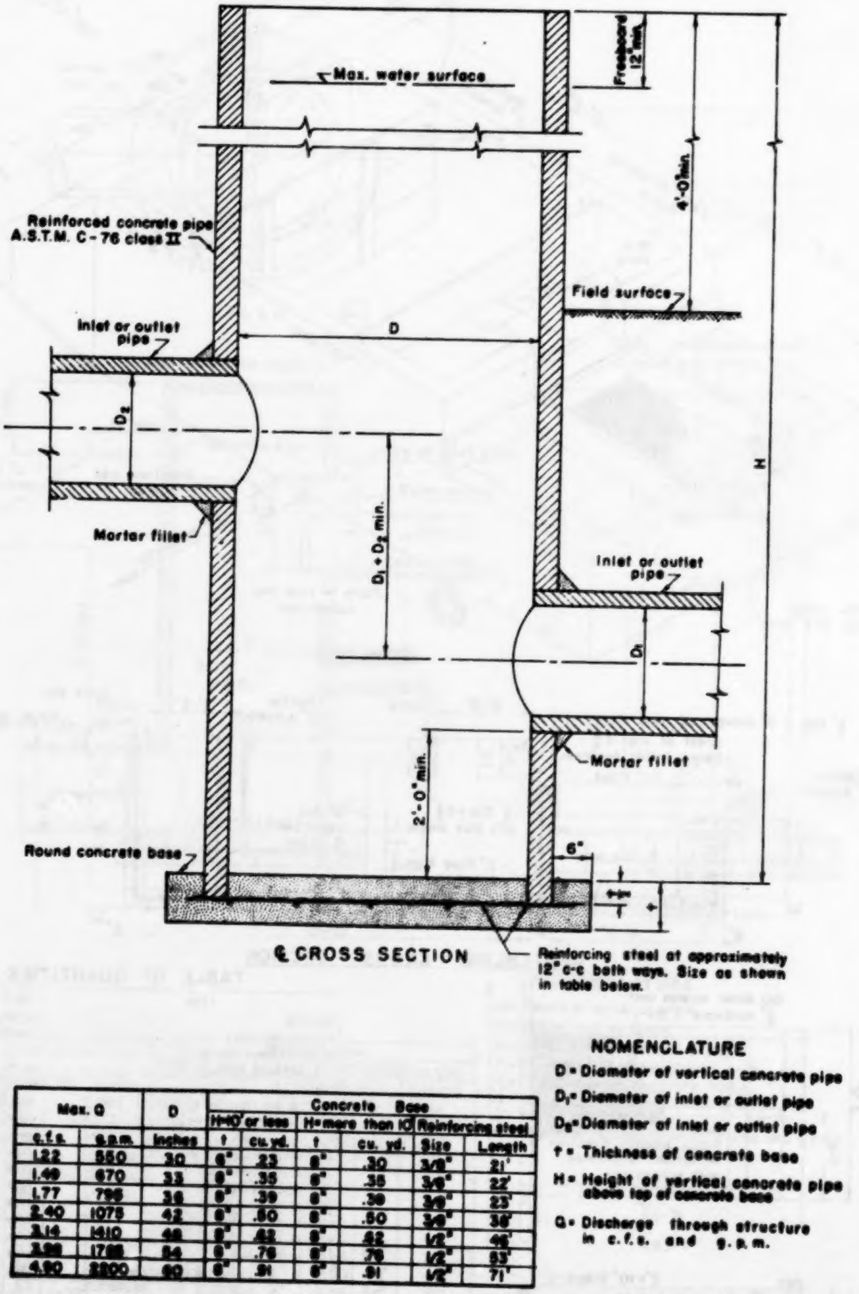
5,0-19,000 20-2

Figure 6-61 Plan for a water desilting box and trash screen


Freeboard 12" min.
Max. water surface
4'-0" min.
Reinforced concrete pipe A.S.T.M. C-76 class II
Field surface
Inlet or outlet pipe
D
D_2
H
Mortar fillet
$D_1 + D_2$ min.
Inlet or outlet pipe
D_1
Mortar fillet
2'-0" min.
Round concrete base
6"
t
℄ CROSS SECTION
Reinforcing steel at approximately 12" c-c both ways. Size as shown in table below.

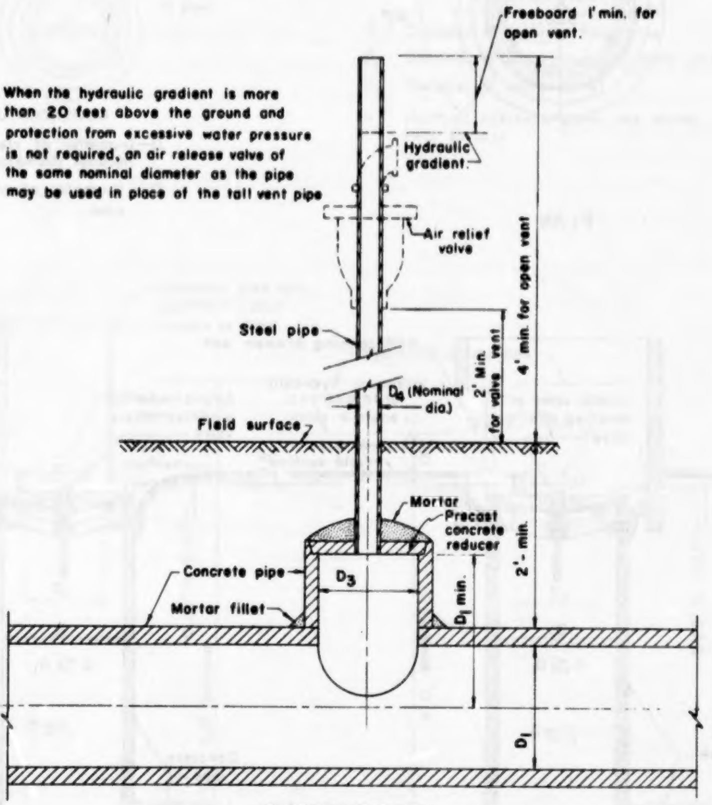
Max. Q		D	Concrete Base					
			H=10' or less		H=more than 10'		Reinforcing steel	
c.f.s.	g.p.m.	Inches	t	cu.yd.	t	cu. yd.	Size	Length
1.22	550	30	6"	.23	8"	.30	3/8"	21'
1.49	670	33	6"	.35	8"	.35	3/8"	22'
1.77	795	36	6"	.39	8"	.39	3/8"	23'
2.40	1075	42	6"	.50	8"	.50	3/8"	38'
3.14	1410	48	6"	.62	8"	.62	1/2"	46'
3.98	1785	54	6"	.76	8"	.76	1/2"	53'
4.90	2200	60	6"	.91	8"	.91	1/2"	71'

NOMENCLATURE

D = Diameter of vertical concrete pipe
D_1 = Diameter of inlet or outlet pipe
D_2 = Diameter of inlet or outlet pipe
t = Thickness of concrete base
H = Height of vertical concrete pipe above top of concrete base
Q = Discharge through structure in c.f.s. and g.p.m.

CONCRETE PIPE SAND TRAP
FOR CONCRETE PIPE LINE
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
1-64 | SO-19000.28-1

Figure 6-62 Plan for a concrete pipe sand trap for concrete pipe



NOTE: When the hydraulic gradient is more than 20 feet above the ground and protection from excessive water pressure is not required, an air release valve of the same nominal diameter as the pipe may be used in place of the tall vent pipe

Freeboard 1' min. for open vent.
Hydraulic gradient.
Air relief valve
Steel pipe
D_4 (Nominal dia.)
Field surface
2' Min. for valve vent
4' min. for open vent
Mortar
Precast concrete reducer
Concrete pipe
Mortar fillet
D_3
D_1 min.
2'- min.
D_1

℄ CROSS SECTION

D_1 Inches	D_3 Min. Inches	D_4 Min. Nominal Dia. Inches
8	6	2
10	8	2
12	10	2
14	10	2
15	12	2
16	12	2 1/2
18	14	2 1/2
20	16	3
21	16	3
24	18	3 1/2

NOMENCLATURE

D_1 - Diameter of underground concrete pipe
D_3 - Diameter of concrete vent pipe
D_4 - Diameter (nominal) of steel vent pipe

VENT FOR CONCRETE PIPE LINES

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

1-64
SO-19,000.33-1

Figure 6-63 Plan for a vent for concrete pipelines

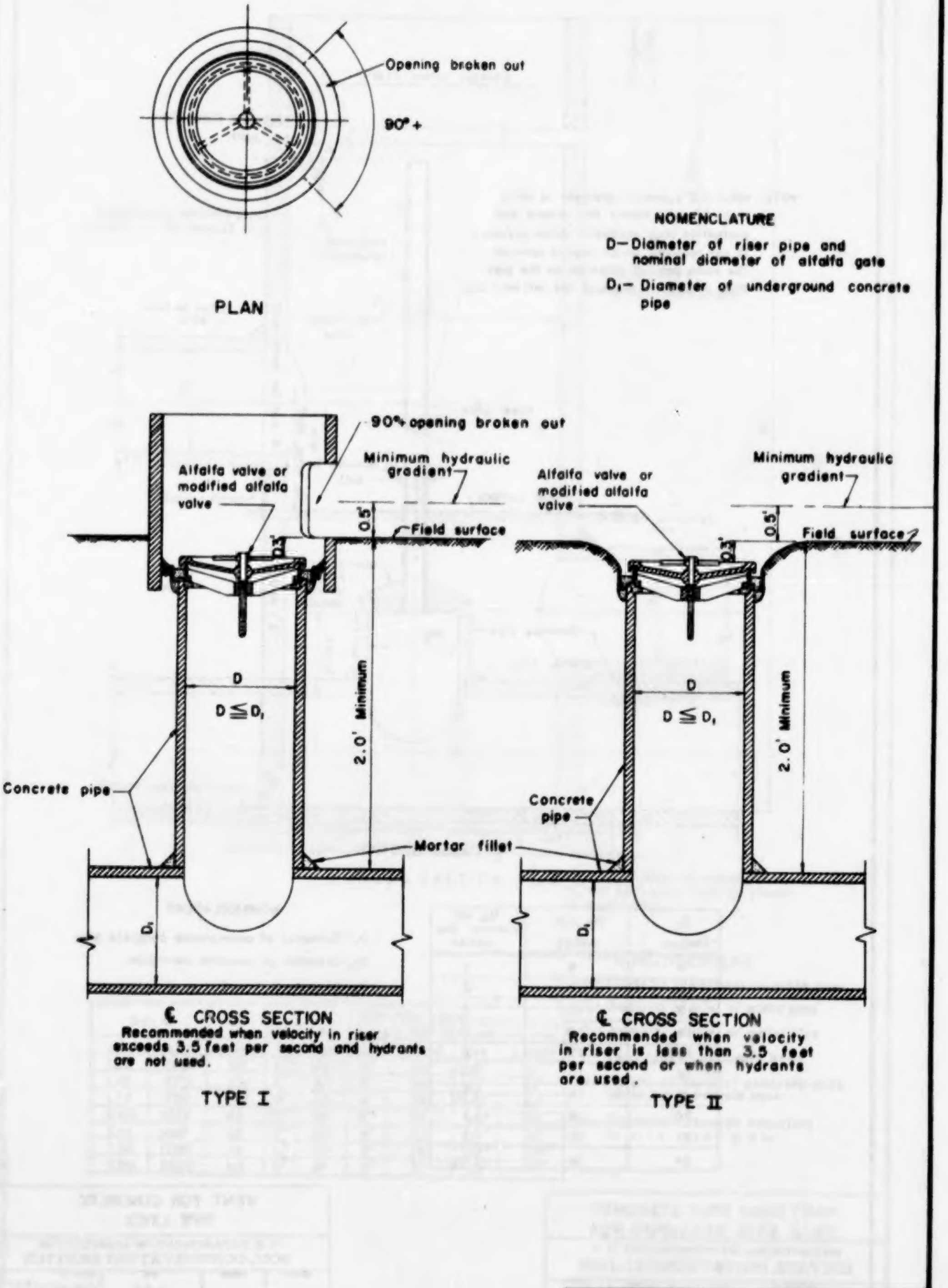

Opening broken out
90°+
PLAN
NOMENCLATURE
D—Diameter of riser pipe and nominal diameter of alfalfa gate
D₁—Diameter of underground concrete pipe
90° opening broken out
Minimum hydraulic gradient
Alfalfa valve or modified alfalfa valve
0.5'
0.3'
Field surface
D
D ≦ D₁
2.0' Minimum
Concrete pipe
Mortar fillet
D₁
℄ CROSS SECTION
Recommended when velocity in riser exceeds 3.5 feet per second and hydrants are not used.
TYPE I
Minimum hydraulic gradient
Alfalfa valve or modified alfalfa valve
0.5'
0.3'
Field surface
D
D ≦ D₁
2.0' Minimum
Concrete pipe
D₁
℄ CROSS SECTION
Recommended when velocity in riser is less than 3.5 feet per second or when hydrants are used.
TYPE II

Figure 6-64 Plan for an alfalfa valve outlet on a concrete pipeline

ALFALFA VALVE or MODIFIED ALFALFA VALVE OUTLET for CONCRETE PIPE LINES
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
1-64
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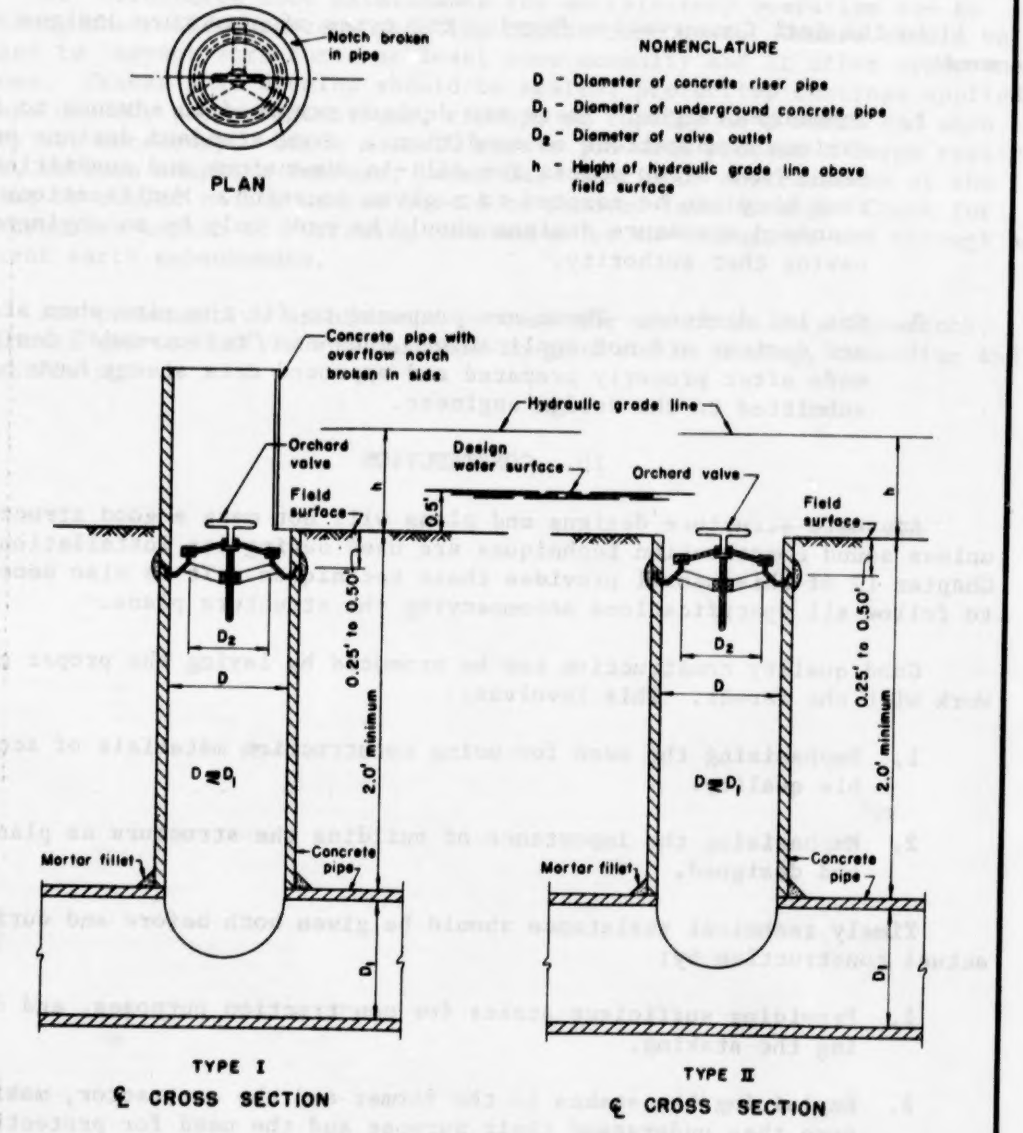
Notch broken in pipe
PLAN
NOMENCLATURE
D - Diameter of concrete riser pipe
D₁ - Diameter of underground concrete pipe
D₂ - Diameter of valve outlet
h - Height of hydraulic grade line above field surface
Concrete pipe with overflow notch broken in side
Hydraulic grade line
Orchard valve
Design water surface
0.5'
h
Field surface
D₂
D
0.25' to 0.50'
2.0' minimum
D ≅ D₁
Mortar fillet
Concrete pipe
D₁
TYPE I
℄ CROSS SECTION
Orchard valve
Field surface
TYPE II
℄ CROSS SECTION

Figure 6-65 Plan for an orchard valve outlet on a concrete pipeline

ORCHARD VALVE OUTLET FOR CONCRETE PIPE LINES

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

1-64
5,0-19,000.30-1

reinforced concrete, and location of construction joints are examples of required detail. Detailed designs are the responsibility of the engineer.

In the Soil Conservation Service two types of structure designs are used:

1. Standard designs. These are designs prepared in advance to fit various combinations of conditions. Some standard designs or plans have blank spaces for fill-in dimensions and quantities, thus they can be adapted to a given location. Modifications in standard structure designs should be made only by an engineer having that authority.

2. Special designs. These are prepared to fit the site when standard designs are not applicable. They are "tailor-made" designs, made after properly prepared and approved data sheets have been submitted to the design engineer.

20. CONSTRUCTION

Adequate structure designs and plans will not make a good structure unless sound construction techniques are used during its installation. Chapter 17 of this manual provides these techniques. It is also necessary to follow all specifications accompanying the structure plans.

Good quality construction can be promoted by laying the proper groundwork with the farmer. This involves:

1. Emphasizing the need for using construction materials of acceptable quality.

2. Emphasizing the importance of building the structure as planned and designed.

Timely technical assistance should be given both before and during the actual construction by:

1. Providing sufficient stakes for construction purposes, and checking the staking.

2. Explaining the stakes to the farmer and the contractor, making sure they understand their purpose and the need for protecting them.

3. Providing the farmer and contractor with plans and specifications prior to construction.

4. Explaining the construction details to the farmer or contractor.

5. Providing timely supervision and checking during the construction period.

21. MAINTENANCE

All structures need maintenance for satisfactory operation and to prolong their life, thereby reducing replacement cost. Owners should be urged to inspect structures at least once annually and at other opportune times. Cracks that develop should be sealed, protective coatings applied where needed, and modifications, riprap, or repairs made where and when they are necessary. Often a small repair job will prevent a large repair job, or even complete failure, later on. Debris or obstructions at the inlet or outlet of structures should be removed immediately. Check for destructive action of burrowing rodents under the structure and through adjacent earth embankments.

For preventative maintenance protect the structure from livestock. Maintain all earthfills and channels in good sod by mowing, reseeding and fertilizing.

ENGINEERING FIELD MANUAL

CHAPTER 7. GRASSED WATERWAYS AND OUTLETS

Compiled by: J. J. Coyle, Agricultural Engineer, SCS, Fort Worth, Texas

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ENGINEERING FIELD MANUAL

CHAPTER 7. GRASSED WATERWAYS AND OUTLETS

1. GENERAL

DEFINITION

Grassed waterways and outlets are natural or constructed waterways shaped to required dimensions and vegetated for safe disposal of runoff from a field, diversion, terrace or other structures.

INTRODUCTION

The grass-lined waterway is one of the basic conservation practices commonly used by farmers. When rainfall exceeds the rate or volume at which the soil can take in and store moisture, surplus water will pass over the land in the form of runoff. Since the success of any soil conservation program depends on the removal of this surplus water without undue erosion, the area needed for waterways should be dedicated to this purpose and consideration of the production of forage should be secondary. This practice is applicable only to those areas where rainfall or irrigation provides the moisture needed to grow and sustain a good grass cover.

The satisfactory performance of a vegetated waterway depends on it having the proper shape, as well as the preparation of the area in a manner to provide conditions favorable to vegetative growth. Between the time of seeding the cover and the actual establishment, a waterway is unprotected and subject to considerable damage unless special protection is provided. Waterways subject to constant or prolonged flows require special supplemental treatment, such as grade control structures, stone centers, or subsurface drainage capable of carrying such flows. After establishment, protective vegetative cover must be maintained.

Vegetated outlets and waterways are used for the following purposes:

1. As outlets for diversions and terraces.

2. As outlets for surface and subsurface drainage systems on sloping land.

3. To dispose of water collected by road ditches or discharged through culverts.

4. To rehabilitate natural draws carrying concentrations of runoff.

PROTECTION

The waterway or outlet may be protected by using a combination of the following steps that best fits the needs of the site.

1. Construct the waterway in advance of any other channels that will discharge into it.
2. Divert all flow from the waterway during establishment period.
3. Establish the vegetative cover according to recommended techniques.
    a. Protect the channel seeding with mulch (manure, stubble, straw, jute netting, or wired and staked mulch).
    b. Sod the channel.
    c. Use a portable or temporary sprinkler line to irrigate the new seeding or sodding to insure and hasten establishment.
4. Carry prolonged flow in a subsurface drainage system or in a surface protected section such as a stone center.
5. Reduce the required capacity by dividing the runoff between two or more outlets.
6. Use stable natural waterways where possible.
7. Maintain vegetative cover by mowing, spraying, fertilizing, and performing other maintenance work as needed.

SHAPE OR CROSS SECTION

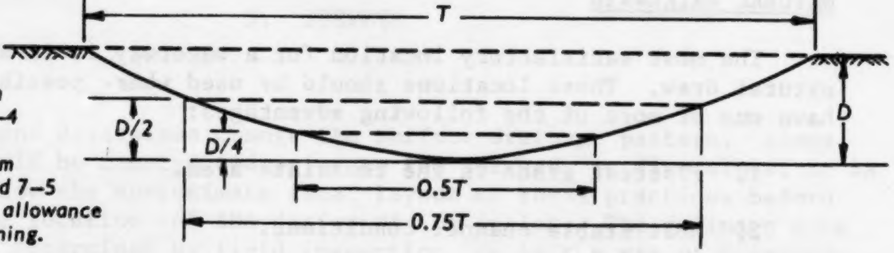
Vegetated waterways may be built to three general shapes or cross sections--parabolic, trapezoidal, or "V" shaped. Parabolic waterways are the most common and generally are the most satisfactory. It is the shape ordinarily found in nature. Small flows are less likely to meander. Most waterways constructed with a trapezoidal section tend to revert to a parabolic cross section. The cross section should be designed to permit easy crossing of equipment where necessary. Typical waterway cross sections are shown in Figure 7-1.

WATERSHED TREATMENT

The successful vegetated waterway is dependent on good conservation treatment on its watershed. The better the erosion control in the watershed, the less silting there will be in the waterway. Good conservation practices also reduce the peak rate of runoff and the volume of water to be carried by the waterway.

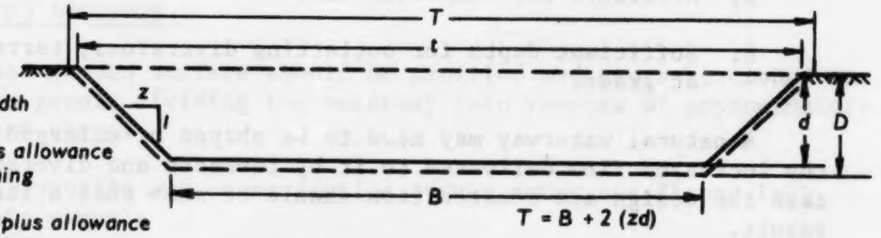
2. LOCATION

The following locations for waterways are discussed in the order of preference:



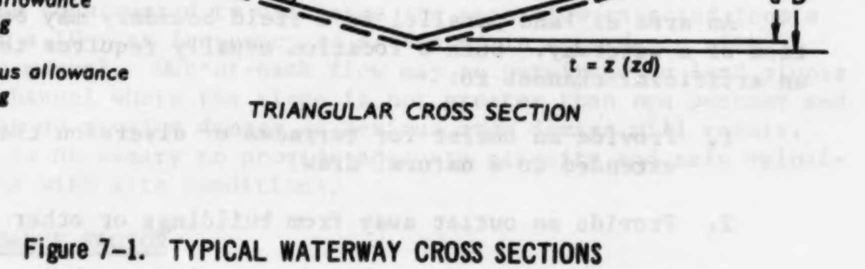
T = design top width from Exhibits 7–4 and 7–5
D = design depth from Exhibits 7–4 and 7–5
Both values include allowance for the vegetative lining.

PARABOLIC CROSS SECTION



B = design bottom width
d = design depth
D = design depth plus allowance for vegetative lining
t = design top width
T = design top width plus allowance for vegetative lining
z = side slope ratio

TRAPEZOIDAL CROSS SECTION



d = design depth
D = design depth plus allowance for vegetative lining
t = design top width
T = design top width plus allowance for vegetative lining
z = side slope ratio

TRIANGULAR CROSS SECTION

Figure 7–1. TYPICAL WATERWAY CROSS SECTIONS

NATURAL WATERWAYS

The most satisfactory location for a waterway is in a well vegetated natural draw. These locations should be used where possible since they have one or more of the following advantages:

1. Flattest grade in the immediate area.
2. Most stable channel conditions.
3. Adequate capacity.
4. Soil and moisture conditions most favorable to vegetative growth.
5. Available for immediate use.
6. Sufficient depth for outletting diversions, terraces and rows at grade.

A natural waterway may need to be shaped or enlarged to accommodate the increased flow delivered to it by terraces and diversions. In this case the design and construction should be such that a stable channel will result.

PASTURE AND MEADOW STRIPS

A pasture or meadow strip may be used in lieu of a constructed or natural channel. However, the surface of such areas should be checked to insure that a uniform surface of adequate width is available to spread the flow, and that the type and density of vegetation is adequate to withstand the expected velocities.

FIELD BOUNDARIES

An area of land parallel to a field boundary may be used for the location of a waterway. Such a location usually requires the construction of an artificial channel to:

1. Provide an outlet for terraces or diversion that cannot be extended to a natural draw.
2. Provide an outlet away from buildings or other critical areas.
3. Avoid the use of a gullied natural draw that would be impractical to control.

ROAD DITCHES

The use of road ditches for the disposal of water should be in conformance with Service requirements and policy in the State.

3. SURVEYS

WATERSHED

Terraces and diversions change the surface drainage pattern. Since the outlet should be constructed prior to the terraces or diversions, it is necessary to know the approximate final layout of these practices before deciding on the location and the design of the outlet. The drainage area divides can be determined by field inspection, or by the use of a stereoscope on an aerial photograph, and sketched on the photograph for measurement. It may be desirable to run one or more terrace lines or contour lines or make a topographic map to determine the location of a waterway to serve a terrace system.

PROFILE AND CROSS SECTIONS

The original ground surface should be profiled and cross sectioned in enough detail to permit dividing the waterway into reaches of approximately uniform slope and shape.

For typical profile and cross section survey notes see Figure 1-23, Chapter 1 of this manual.

4. DESIGN

The design of a waterway is the determination of channel dimensions that will carry the estimated flow without damage to the channel or its lining. Vegetative linings vary in their protective ability according to type and density. Therefore, safe velocities under various conditions are a matter for careful consideration.

DESIGN STORM FREQUENCY

Waterways are constructed to discharge the peak flow expected from a storm of at least a 10-year frequency as estimated in accordance with Chapter 2 of this manual. Out-of-bank flow may be permitted on land slopes parallel to the channel where the slope is not greater than one percent and it is evident that no erosion damage or serious crop damage will result. In every case it is necessary to provide adequate capacity and safe velocities in accordance with site conditions.

VEGETATIVE RETARDANCE FACTOR

The design of a vegetated waterway is more complicated than for a bare channel, since the value for "n" varies where grass linings are used. Tests show that vegetation tends to bend and oscillate under the influence of velocity and depth of flow. Thus, the retardance to flow varies as these factors change.

Research has shown that in both large and small channels, in channels of different cross-sectional shape and bed slope, and with different vegetal covers, the retardance coefficient "n" (Manning's coefficient of roughness) varies with VR. The term VR is the product of velocity and the hydraulic radius. This relationship will be referred to as the "n-VR relationship", which is the recommended basis for vegetated channel design.

The five general retardance curves, designated as A, B, C, D, and E in Exhibit 7-1, have been developed for various cover conditions. The vegetal conditions under which the various retardance values apply are shown in Exhibit 7-2. These cover classifications are based on tests in experimental channels when the covers were green and generally uniform.

Most of the vegetation used in waterways does not exceed 18 inches in height and may be much shorter at times during the year. Therefore, it is recommended that when designing the channel for safe velocity, a retardance not greater than "D" be used. After designing the channel for safe velocity, it must be checked for capacity to accommodate the peak flow under conditions where vegetation gives the highest retardance. The retardance used in this instance is the curve corresponding to the expected vegetal cover and, in most cases, it will be retardance "C", though curve "B" may be used where considered appropriate.

All pertinent design data and computations should be recorded.

DESIGN DATA

The following information is required for designing a waterway:

1. Watershed area in acres, together with the soil characteristics, cover and topography. This information is used to estimate runoff by the procedures set forth in Chapter 2 of this manual.
2. Grade of the proposed waterway in percent slope (this is the fall in feet per 100 feet of length).
3. Vegetal cover adapted to site conditions.
4. Erodibility of the soil in the waterway.
5. Expected height at which vegetative cover will be maintained.
6. The permissible velocity for the conditions encountered.
7. Allowance for space that will be occupied by the vegetative lining.
8. Allowance for freeboard, if required by State Standards and Specifications.

NON-EROSIVE VELOCITY OF FLOW

In designing grassed waterways, care must be taken to insure that the design velocity is well within the limits of permissible velocities given in Exhibit 7-3. These values apply to average, uniform stands of each type of cover.

For erosion resistant soils, the prevailing range of maximum velocities used for design is from 3.0 to 7.0 feet per second. The maximum permissible velocity will be determined by individual site conditions:

1. A velocity of 3.0 feet per second should be the maximum, where because of shade, soils, or climate, only a sparse cover can be established or maintained.

2. A velocity of 3.0 to 4.0 feet per second should be used under normal conditions where the vegetation is to be established by seeding.

3. A velocity of 4.0 to 5.0 feet per second should be used only in areas where a dense, vigorous sod is obtained quickly or where water can be diverted out of the waterway while the vegetation is being established.

4. A velocity of 5.0 to 6.0 feet per second may be used on well established sod of good quality.

5. A velocity of 6.0 to 7.0 feet per second may be used only on established sod of excellent quality, and only under special circumstances in which the flow cannot be handled at a lower velocity. Under these conditions, special maintenance will be required.

If the vegetative lining is supplemented by stone centers, Figure 7-2, or other highly resistant materials, the slope and velocity ranges given in Exhibit 7-3 may be increased in accordance with local technical guides.

DESIGN PROCEDURES

Waterways are frequently planned where the slope is variable and where there is a wide difference in the watershed area at various points along the channel. In such cases, the waterway is designed in reaches. A reach is usually a portion of the watershed having a near-uniform slope and drainage area. A point of significant break in slope is a point of division between two reaches. The point of entrance of a diversion or other tributary where the watershed area is significantly increased also may be a point of division between two reaches. Where there is a significant difference in velocity or capacity between adjoining reaches, it may be necessary to install a transition section between them.

When the limits of two or more reaches have been determined, each reach is designed separately by procedures given in the following paragraphs.

Exhibits 7-4 and 7-5 have been prepared to simplify the determination of waterway size for given site conditions. The tables conform to the principles outlined in SCS-TP-61, "Handbook of Channel Design for Soil and Water Conservation."

The following example demonstrates how to use the exhibits to design a parabolic channel.

Problem: Determine the safe velocity and dimensions for stability and capacity for a waterway with parabolic cross section.

Given: Runoff $Q = 55$ c.f.s.
Grade = 5 percent
Vegetative Cover Bluegrass
Soil Moderately erodible
Condition of Vegetation
Good stand--Mowed (3" - 4") = "D" curve retardance (from Exhibit 7-2)
Good stand--Headed (6" - 12") = "C" curve retardance (from Exhibit 7-2)
Permissible Velocity V_1 = 4.0 f.p.s. (from Exhibit 7-3)

Horizontally opposite 55 c.f.s. in Exhibit 7-5 (5 percent slope) in the columns headed $V_1 = 4.0$ f.p.s., find $T = 32.6$ feet, $D = 0.75$ foot and $V_2 = 3.33$ f.p.s. Therefore a waterway with parabolic cross section, a top width of 32.6 feet, and a depth of 0.75 foot will carry 55 c.f.s. at a maximum velocity of 4 feet per second when the vegetative lining is short (3" to 4" in height) and 3.33 feet per second when vegetative lining is tall (6" to 12"). This complies with the requirements for safe velocity when vegetation is short ("D" retardance) and capacity when vegetation is tall ("C" retardance).

The dimensions given by Exhibits 7-4 and 7-5 are the minimums required to carry the actual flow. These tables do not include a factor for extra depth required for space occupied by vegetation and sedimentation. Where State Standards require such a factor, it should be added to the dimensions given in these tables. It is important that the depth be adequate to permit unimpeded discharge from terraces, diversions, and rows.

If the waterway must be crossed with farm equipment, consideration should be given to the need for increased width. Large combines, corn pickers, cotton pickers and similar equipment may require a significant increase in width over that needed for hydraulic capacity and freeboard. This problem deserves careful study in each work unit area so that the proper modifications are made in waterway width and side slopes to meet the needs of equipment common to the locality.

DRAINAGE OF WATERWAYS

Vegetated waterways, to be effective, must not be subjected to low flows of long duration nor kept wet for long periods. A tile system or other means of providing drainage and protecting the center of the waterway should be considered where prolonged low flows or wet conditions prevail.

Tile Drains

Tile lines should parallel the center of the vegetated waterway but be offset from the centerline at least one-fourth the top width of the waterway. Two lines may be required in some cases, one each side of the center. The principles outlined in Chapter 14 of this manual should be followed in designing and installing the tile lines. The tile line(s) may be outletted through a drop structure at the end of the waterway if there is a significant difference in elevation between the tile and channel outlets, or through a standard tile outlet.

Stone Center Drains

In sections where field stones or other sources of rock are plentiful a stone center drain may be the best solution to problems of prolonged flow and wetness. These drains are installed as shown in Figure 7-2. Required stone size in relation to slope of waterway and depth of flow can be determined from the nomograph, Exhibit 7-6.

5. CONSTRUCTION

EQUIPMENT

Many kinds of farming and construction equipment are adapted to the construction of waterways. However it may be necessary to use equipment that will load and transport the excavated material to locations where it is needed. These points of need might be low spots in the surrounding field or washes in the waterway that need filling. Small scrapers that can be pulled by farm tractors are satisfactory units for waterway construction. However, large scrapers, bulldozers and motor patrols are excellent types of equipment for constructing waterways and should be used whenever available.

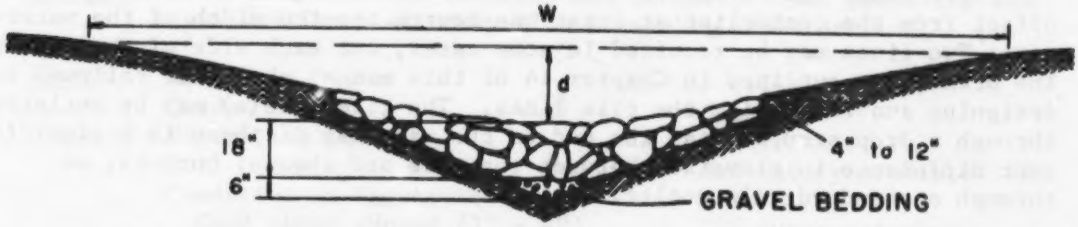
SITE PREPARATION

The waterway should be staked for construction. All trees, stumps, brush and similar material should be removed from the site and disposed of in such manner as to not interfere with proper functioning of the waterway. For typical design and construction survey notes see Figure 1-25, Chapter 1 of this manual.

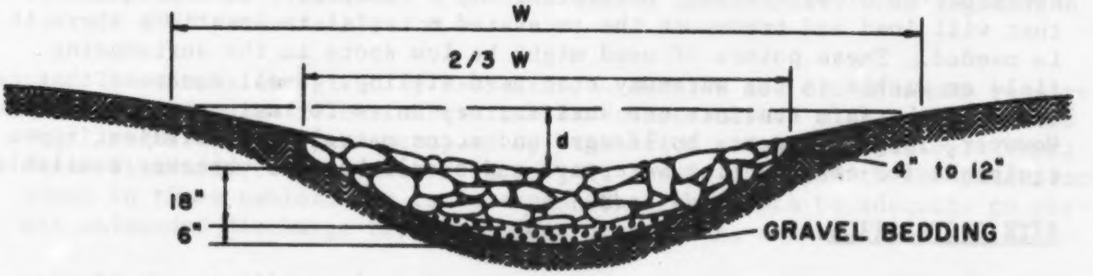
EXCAVATION

The soil removed from the waterway should be deposited where it will not interfere with flow of water into the waterway. Normally it can be used to fill low spots in the surrounding field.

The topsoil may be saved and spread in the constructed waterway if necessary for obtaining a good vegetative cover. Where this is done the waterway should be over-excavated to allow for replacement of the topsoil without encroaching on the design cross section.


W
d
18"
6"
4" to 12"
GRAVEL BEDDING

Waterway with stone center drain
V section shaped by motor patrol


W
2/3 W
d
18"
6"
4" to 12"
GRAVEL BEDDING

Waterway with stone center drain
Rounded section shaped by bulldozer

Figure 7-2 Waterway with stone center

DRAINAGE

Special drainage features such as tile drains, tile outlet structures, and rock centers may be installed when excavation has been completed as planned.

ESTABLISHING VEGETATION

Waterway vegetation is established usually by seeding or by planting the roots or other vegetative parts of the selected plants. In the more critical sections of some waterways it may be desirable to provide immediate protection by transplanting a complete sod cover.

Jute, plastic, or paper mesh and straw or hay mulch may be used to protect the center portion or entire width of a waterway until the vegetation becomes established.

All seeding, planting and sodding should conform to sound agronomic recommendations as given in the local Technical Guide.

6. MAINTENANCE

Timely maintenance is important to keep a waterway in good working condition. Fertilizing and mowing or spraying for weed control should be done frequently enough to keep the vegetation in vigorous condition. Grazing, if permitted, should be rigidly controlled. Livestock should be excluded during wet conditions.

Vehicular traffic should be excluded from the waterway.

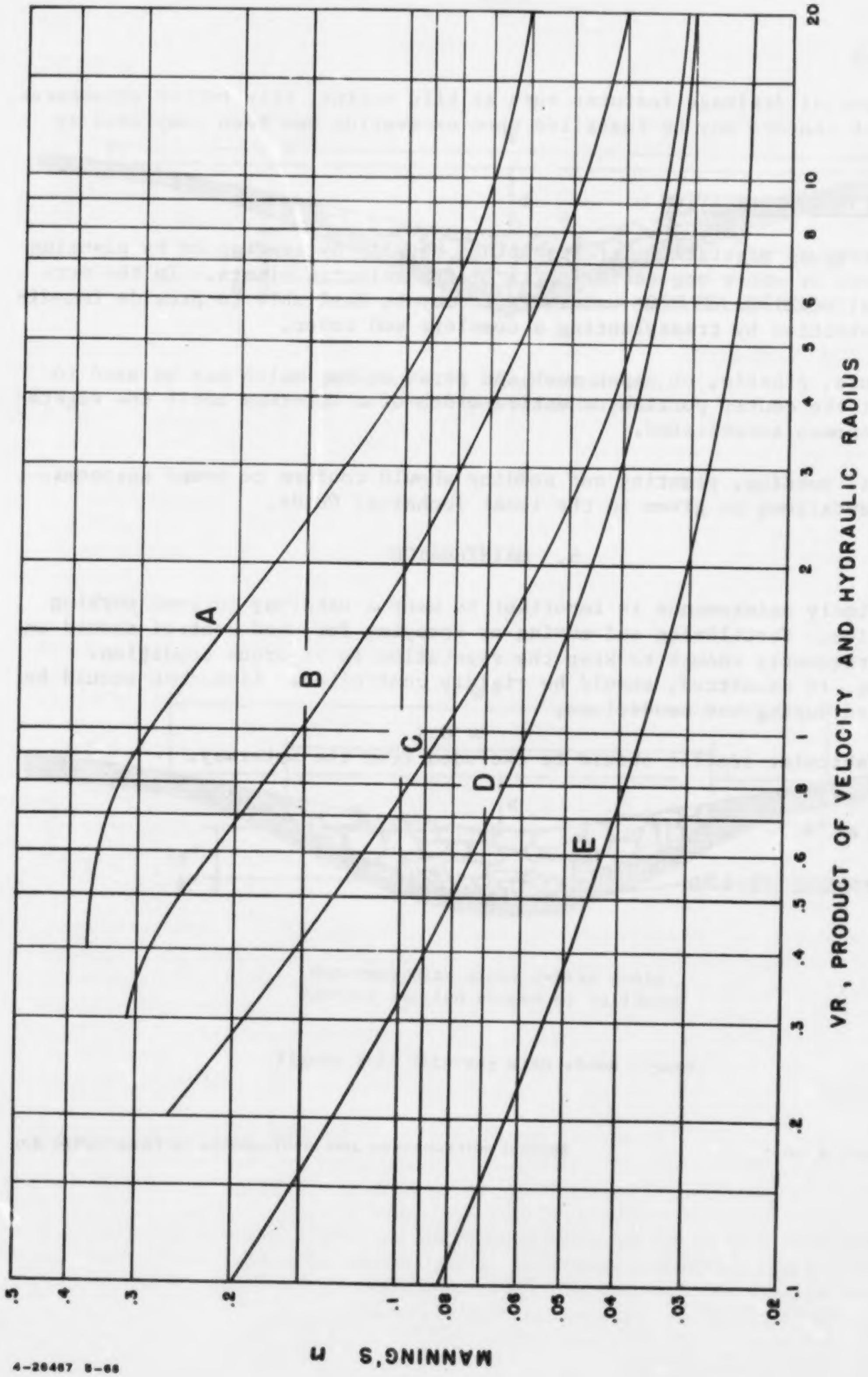


Exhibit 7-1. Manning's "n" related to velocity, hydraulic radius, and vegetal retardance.

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Retar-dance	Cover	Condition
A	Reed canarygrass	Excellent stand, tall (average 36 inches)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36 inches)
B	Smooth bromegrass	Good stand, mowed (average 12 to 15 inches)
	Bermudagrass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 inches)
	Lespedeza sericea	Good stand, not woody, tall (average 19 inches)
	Grass-legume mixture--Timothy, smooth bromegrass, or orchard grass	Good stand, uncut (average 20 inches)
	Reed canarygrass	Good stand, mowed (average 12 to 15 inches)
	Tall fescue, with bird's foot trefoil or lodino	Good stand, uncut (average 18 inches)
	Blue grama	Good stand, uncut (average 13 inches)
C	Bahia	Good stand, uncut (6 to 8 inches)
	Bermudagrass	Good stand, mowed (average 6 inches)
	Redtop	Good stand, headed (15 to 20 inches)
	Grass-legume mixture--summer (Orchard grass, red-top, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Red fescue	Good stand, headed (12 to 18 inches)
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture--fall, spring (Orchard grass, redtop, Italian ryegrass, and common lespedeza).	Good stand, uncut (4 to 5 inches)
	Lespedeza sericea	After cutting to 2-inch height. Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-inch height.
	Bermudagrass	Burned stubble.

Exhibit 7-2. Classification of vegetation cover as to degree of retardance.

Cover	Slope range 2/ (percent)	Permissible velocity 1/	
		Erosion resistant soils (ft.per sec.)	Easily eroded soils (ft.per sec.)
Bermudagrass	0-5 5-10 over 10	8 7 6	6 5 4
Bahia Buffalograss Kentucky bluegrass Smooth brome Blue grama Tall fescue	0-5 5-10 over 10	7 6 5	5 4 3
Grass mixtures Reed canarygrass	2/ 0-5 5-10	5 4	4 3
Lespedeza sericea Weeping lovegrass Yellow bluestem Redtop Alfalfa Red fescue	3/ 0-5	3.5	2.5
Common lespedeza 4/ Sudangrass 4/	5/ 0-5	3.5	2.5

1/ Use velocities exceeding 5 feet per second only where good covers and proper maintenance can be obtained.

2/ Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

3/ Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

4/ Annuals--use on mild slopes or as temporary protection until permanent covers are established.

5/ Use on slopes steeper than 5 percent is not recommended.

Exhibit 7-3. Permissible velocities for channels lined with vegetation

4-38487 5-88

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 0.25 Percent

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	11.3	3.27	1.00																								
30	13.2	3.09	1.09																								
35	15.2	3.01	1.13																								
40	17.3	2.99	1.15	12.1	3.61	1.36																					
45	19.3	2.94	1.18	13.4	3.49	1.42																					
50	21.4	2.93	1.18	14.7	3.41	1.48																					
55	23.5	2.92	1.19	16.1	3.38	1.50																					
60	25.5	2.89	1.21	17.5	3.35	1.52																					
65	27.6	2.89	1.21	18.8	3.30	1.56																					
70	29.7	2.89	1.21	20.2	3.28	1.57	14.4	3.98	1.81																		
75	31.7	2.87	1.23	21.6	3.27	1.58	15.3	3.91	1.86																		
80	33.8	2.87	1.23	23.0	3.26	1.58	16.3	3.90	1.87																		
90	38.0	2.87	1.23	25.8	3.25	1.60	18.1	3.80	1.94																		
100	42.1	2.85	1.24	28.6	3.23	1.61	20.0	3.76	1.98																		
110	46.3	2.85	1.24	31.4	3.22	1.62	21.9	3.73	2.01																		
120	50.4	2.84	1.25	34.1	3.20	1.64	23.9	3.73	2.00	17.0	4.47	2.34															
130	54.6	2.85	1.24	36.9	3.19	1.64	25.8	3.70	2.02	18.3	4.42	2.39															
140	58.7	2.84	1.25	39.7	3.19	1.65	27.7	3.68	2.04	19.6	4.37	2.43															
150	62.9	2.85	1.25	42.5	3.19	1.65	29.6	3.67	2.06	20.9	4.33	2.47															
160	67.0	2.84	1.25	45.3	3.18	1.65	31.6	3.68	2.05	22.2	4.30	2.50															
170	71.1	2.84	1.26	48.1	3.18	1.65	33.5	3.66	2.07	23.5	4.27	2.53	18.5	4.95	2.76												
180	75.3	2.84	1.25	50.9	3.18	1.66	35.4	3.65	2.08	24.8	4.24	2.55	19.5	4.90	2.80												
190	79.4	2.84	1.26	53.7	3.18	1.66	37.4	3.66	2.07	26.1	4.22	2.57	20.5	4.87	2.84												
200	83.5	2.84	1.26	56.5	3.18	1.66	39.3	3.65	2.08	27.5	4.23	2.56	21.5	4.83	2.87												
220	91.8	2.84	1.26	62.1	3.18	1.66	43.2	3.65	2.08	30.1	4.19	2.60	23.5	4.77	2.92												
240	100.0	2.83	1.26	67.6	3.17	1.67	47.0	3.63	2.10	32.7	4.15	2,64	25.5	4.72	2.97												
260	108.3	2.84	1.26	73.2	3.17	1.67	50.9	3.63	2.10	35.4	4.15	2.64	27.5	4.68	3.01	21.4	5.50	3.29									
280	116.6	2.84	1.26	78.8	3.17	1.67	54.8	3.63	2.10	38.1	4.14	2.64	29.5	4.64	3.05	22.9	5.44	3.35									
300	124.8	2.84	1.26	84.4	3.17	1.67	58.6	3.62	2.11	40.8	4.14	2.65	31.5	4.61	3.08	24.5	5.42	3.37									

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 1 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 0.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	10.2	2.28	0.95																								
20	13.3	2.18	1.02																								
25	16.5	2.15	1.05	10.5	2.60	1.35																					
30	19.7	2.12	1.06	12.4	2.51	1.42	9.5	2.91	1.60																		
35	22.8	2.09	1.09	14.3	2.45	1.48	10.9	2.81	1.69																		
40	26.0	2.08	1.09	16.3	2.44	1.49	12.3	2.74	1.76																		
45	29.2	2.08	1.10	18.2	2.41	1.52	13.7	2.69	1.81																		
50	32.4	2.08	1.10	20.2	2.40	1.53	15.1	2.64	1.86	11.1	3.22	2.07															
55	35.6	2.08	1.11	22.1	2.38	1.55	16.6	2.64	1.86	12.0	3.11	2.18															
60	38.8	2.08	1.11	24.1	2.38	1.55	18.0	2.61	1.90	13.0	3.07	2.23															
65	42.0	2.08	1.11	26.0	2.36	1.57	19.5	2.61	1.89	14.0	3.03	2.27															
70	45.2	2.08	1.11	28.0	2.36	1.57	20.9	2.59	1.92	15.0	3.01	2.31															
75	48.4	2.08	1.11	29.9	2.35	1.59	22.4	2.59	1.92	16.0	2.98	2.34	12.7	3.48	2.52												
80	51.6	2.08	1.11	31.9	2.36	1.58	23.8	2.58	1.94	17.0	2.96	2.36	13.4	3.41	2.60												
90	57.9	2.07	1.12	35.8	2.35	1.59	26.7	2.56	1.96	19.1	2.95	2.37	15.0	3.37	2.64												
100	64.3	2.07	1.11	39.7	2.34	1.60	29.6	2.55	1.97	21.1	2.92	2.42	16.5	3.31	2.72	13.3	3.77	2.96									
110	70.7	2.08	1.11	43.6	2.34	1.61	32.6	2.56	1.96	23.2	2.92	2.42	18.1	3.29	2.75	14.5	3.70	3.05									
120	77.0	2.07	1.12	47.5	2.33	1.61	35.5	2.56	1.97	25.2	2.89	2.45	19.6	3.24	2.81	15.7	3.64	3.12									
130	83.4	2.08	1.12	51.5	2.34	1.61	38.4	2.55	1.98	27.3	2.90	2.45	21.2	3.23	2.82	16.9	3.60	3.18									
140	89.7	2.08	1.12	55.4	2.34	1.61	41.3	2.55	1.98	29.3	2.88	2.47	22.8	3.22	2.84	18.1	3.56	3.23									
150	96.0	2.08	1.12	59.3	2.34	1.61	44.2	2.55	1.99	31.4	2.88	2.47	24.3	3.19	2.88	19.4	3.56	3.23	15.5	4.09	3.52						
160	102.3	2.08	1.12	63.2	2.34	1.61	47.1	2.54	1.99	33.5	2.89	2.47	25.9	3.19	2.88	20.6	3.53	3.27	16.4	4.02	3.60						
170	108.6	2.08	1.12	67.1	2.34	1.62	50.0	2.54	1.99	35.5	2.87	2.48	27.5	3.19	2.89	21.9	3.54	3.27	17.4	4.01	3.62						
180	114.9	2.08	1.12	70.9	2.33	1.62	52.9	2.54	1.99	37.6	2.88	2.48	29.1	3.19	2.89	23.1	3.51	3.30	18.3	3.96	3.69						
190	121.2	2.08	1.12	74.8	2.33	1.62	55.8	2.54	2.00	39.6	2.87	2.49	30.6	3.16	2.92	24.3	3.49	3.34	19.3	3.96	3.70						
200	127.4	2.08	1.13	78.7	2.33	1.62	58.7	2.54	2.00	41.7	2.87	2.49	32.2	3.16	2.93	25.6	3.50	3.33	20.2	3.91	3.77	16.8	4.48	3.96			
220	140.0	2.08	1.13	86.5	2.33	1.62	64.5	2.54	2.00	45.8	2.87	2.50	35.4	3.16	2.93	28.1	3.49	3.35	22.1	3.87	3.83	18.3	4.39	4.08			
240	152.6	2.08	1.13	94.3	2.33	1.63	70.3	2.54	2.01	49.9	2.86	2.51	38.6	3.16	2.93	30.6	3.48	3.36	24.1	3.87	3.84	19.9	4.36	4.12			
260	165.2	2.08	1.13	102.1	2.33	1.63	76.1	2.54	2.01	54.0	2.86	2.51	41.7	3.15	2.95	33.1	3.47	3.38	26.0	3.84	3.88	21.5	4.34	4.15			
280	177.7	2.08	1.13	109.8	2.33	1.63	81.9	2.54	2.01	58.2	2.87	2.50	44.9	3.15	2.95	35.6	3.46	3.39	28.0	3.84	3.88	23.0	4.28	4.24	19.0	4.88	4.50
300	190.3	2.08	1.13	117.6	2.33	1.63	87.7	2.54	2.01	62.3	2.86	2.51	48.0	3.14	2.97	38.1	3.45	3.40	29.9	3.82	3.92	24.6	4.27	4.26	20.2	4.80	4.61

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 2 of 14)

4-28487 5-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 0.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.7	1.76	0.92	8.0	2.22	1.24																					
20	18.2	1.75	0.93	10.4	2.10	1.35																					
25	22.6	1.73	0.95	12.8	2.03	1.42	9.5	2.33	1.66																		
30	27.1	1.73	0.95	15.3	2.02	1.44	11.2	2.25	1.76	8.9	2.56	1.94															
35	31.5	1.72	0.96	17.8	2.01	1.45	13.0	2.23	1.79	10.2	2.47	2.05															
40	36.0	1.72	0.96	20.2	1.98	1.48	14.8	2.21	1.81	11.6	2.44	2.09															
45	40.4	1.71	0.96	22.7	1.98	1.49	16.5	2.17	1.86	12.9	2.39	2.16															
50	44.9	1.72	0.96	25.2	1.98	1.49	18.3	2.16	1.87	14.3	2.38	2.18	10.6	2.82	2.47												
55	49.3	1.72	0.96	27.6	1.96	1.51	20.1	2.16	1.88	15.7	2.37	2.19	11.6	2.80	2.51												
60	53.7	1.72	0.97	30.1	1.96	1.51	21.9	2.16	1.89	17.1	2.36	2.20	12.5	2.73	2.61												
65	58.1	1.72	0.97	32.5	1.95	1.52	23.6	2.14	1.92	18.4	2.33	2.25	13.5	2.71	2.63	11.2	3.04	2.83									
70	62.5	1.72	0.97	35.0	1.96	1.52	25.4	2.14	1.92	19.8	2.33	2.25	14.4	2.66	2.71	12.0	3.01	2.87									
75	66.9	1.72	0.97	37.4	1.95	1.53	27.2	2.14	1.92	21.2	2.33	2.26	15.4	2.65	2.73	12.8	2.99	2.91									
80	71.2	1.71	0.97	39.9	1.95	1.53	29.0	2.14	1.92	22.5	2.31	2.29	16.4	2.65	2,74	13.5	2.92	3.01									
90	80.0	1.71	0.97	44.8	1.95	1.53	32.5	2.12	1.94	25.3	2.31	2.29	18.4	2.63	2.76	15.1	2.89	3.07	12.4	3.26	3.30						
100	88.8	1.72	0.98	49.7	1.95	1.54	36.1	2.13	1.94	28.1	2.31	2.29	20.4	2.62	2.78	16.7	2.86	3.11	13.7	3.22	3.36						
110	97.6	1.72	0.98	54.7	1.95	1.53	39.7	2.13	1.94	30.8	2.30	2.31	22.4	2.61	2.79	18.3	2.84	3.15	14.9	3.15	3.48						
120	106.3	1.72	0.98	59.6	1.95	1.54	43.2	2.12	1.95	33.6	2.30	2.31	24.4	2.61	2.81	19.9	2.82	3.18	16.2	3.13	3.52	13.4	3,49	3.81			
130	115.0	1.72	0.98	64.5	1.95	1.54	46.8	2.12	1.95	36.4	2.30	2.31	26.3	2.58	2.85	21.5	2.81	3.20	17.5	3.11	3.55	14.5	3.49	3.82			
140	123.7	1.72	0.98	69.4	1.95	1.54	50.3	2.12	1.96	39.1	2.29	2.33	28.3	2.58	2.85	23.1	2.80	3.22	18.7	3.07	3.63	15.5	3.44	3.91			
150	132.4	1.72	0.98	74.2	1.95	1.55	53.9	2.12	1.95	41.9	2.30	2.32	30.3	2.58	2.86	24.7	2.79	3.24	20.0	3.06	3.65	16.5	3.39	3.98			
160	141.1	1.72	0.98	79.1	1.95	1.55	57.4	2.12	1.96	44.6	2.29	2.33	32.3	2.58	2.86	26.3	2.78	3.26	21.3	3.05	3.67	17.6	3.39	3.98	14.4	3.77	4.37
170	149.7	1.72	0.98	84.0	1.95	1.55	60.9	2.12	1.97	47.4	2.30	2.33	34.3	2.58	2.86	28.0	2.80	3.24	22.6	3.04	3.68	18.6	3.36	4.05	15.3	3.77	4.38
180	158.3	1.72	0.98	88.8	1.95	1.55	64.5	2.12	1.96	50.1	2.29	2.34	36.3	2.58	2.86	29.6	2.79	3.25	23.9	3.04	3.69	19.6	3.33	4.11	16.1	3.73	4.46
190	166.9	1.72	0.98	93.7	1.95	1.55	68.0	2.12	1.97	52.8	2.29	2.34	38.3	2.58	2.86	31.2	2.78	3.26	25.2	3.03	3.70	20.7	3.33	4.10	17.0	3.73	4.45
200	175.5	1.72	0.99	98.5	1.95	1.55	71.5	2.12	1.97	55.6	2.29	2.34	40.2	2.57	2.89	32.8	2.78	3.27	26.5	3.03	3.71	21.7	3.31	4.15	17.8	3.70	4.52
220	192.8	1.72	0.99	108.3	1.95	1.55	78.6	2.12	1.97	61.1	2.29	2.34	44.2	2.57	2.89	36.0	2.77	3.29	29.1	3.02	3.73	23.8	3.29	4.18	19.5	3.67	4.58
240	210.1	1.72	0.99	118.0	1.95	1.56	85.6	2.12	1.98	66.6	2.29	2.35	48.2	2.57	2.89	39.2	2.76	3.31	31.7	3.01	3.75	25.9	3.28	4.22	21.2	3.64	4.63
260	227.3	1.72	0.99	127.7	1.95	1.56	92.7	2.12	1.98	72.1	2.29	2.35	52.2	2.57	2.89	42.5	2.77	3.30	34.3	3.01	3.76	28.0	3.26	4.24	22.9	3.62	4.67
280	244.5	1.72	0.99	137.4	1.95	1.56	99.7	2.12	1.98	77.6	2.29	2.35	56.2	2.57	2.89	45.7	2.76	3.31	36.9	3.00	3.77	30.1	3.25	4.26	24.7	3.63	4.65
300	261.7	1.72	0.99	147.1	1.95	1.56	106.8	2.12	1.98	83.0	2.29	2.36	60.1	2.57	2.90	48.9	2.76	3.32	39.5	3.00	3.78	32.2	3.25	4.28	26.4	3.62	4.68

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 3 of 14)

4-26487 5-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 1.0 Percent

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	15.7	1.55	0.91	9.9	1.80	1.24																					
20	20.9	1.54	0.92	13.0	1.74	1.31	8.8	2.04	1.65																		
25	26.0	1.53	0.93	16.2	1.73	1.32	10.9	1.99	1.70	8.9	2.21	1.87															
30	31.1	1.52	0.94	19.3	1.70	1.35	12.9	1.94	1.78	10.5	2.14	1.98															
35	36.2	1.52	0.94	22.5	1.70	1.36	15.0	1.93	1.80	12.1	2.08	2.06	9.2	2.37	2.37												
40	41.3	1.52	0.95	25.7	1.70	1.36	17.1	1.92	1.81	13.7	2.04	2.12	10.4	2.32	2.45												
45	46.4	1.52	0.95	28.8	1.69	1.37	19.2	1.91	1.82	15.4	2.04	2.12	11.7	2.32	2.46												
50	51.5	1.52	0.95	32.0	1.70	1.37	21.2	1.89	1.85	17.0	2.02	2.16	12.9	2.28	2.52	9.9	2.61	2.86									
55	56.5	1.51	0.95	35.1	1.69	1.38	23.3	1.89	1.86	18.7	2.02	2.16	14.1	2.25	2.57	10.8	2.57	2.93									
60	61.6	1.52	0.95	38.3	1.69	1.37	25.4	1.89	1.86	20.3	2.00	2.19	15.3	2.23	2.61	11.7	2.54	3.00									
65	66.6	1.52	0.96	41.4	1.69	1.38	27.5	1.89	1.86	22.0	2.01	2.19	16.6	2.24	2.60	12.7	2.55	2.98	10.6	2.88	3.16						
70	71.6	1.51	0.96	44.6	1.70	1.38	29.5	1.88	1.88	23.6	1.99	2.21	17.8	2.22	2.63	13.6	2.52	3.03	11.3	2.82	3.26						
75	76.6	1.51	0.96	47.7	1.69	1.38	31.6	1.88	1.88	25.3	2.00	2.21	19.0	2.21	2.66	14.5	2.50	3.08	12.0	2.77	3.35						
80	81.6	1.52	0.96	50.8	1.69	1.38	33.7	1.88	1.88	26.9	1.99	2.22	20.3	2.22	2.64	15.4	2.48	3.11	12.7	2.73	3.43						
90	91.7	1.52	0.96	57.1	1.69	1.39	37.8	1.88	1.89	30.2	1.98	2.24	22.8	2.21	2.65	17.3	2.47	3.13	14.2	2.69	3.49	11.8	2.99	3.78			
100	101.7	1.52	0.96	63.4	1.69	1.39	42.0	1.88	1.89	33.5	1.98	2.24	25.2	2.19	2.69	19.2	2.47	3.14	15.7	2.67	3.55	13.0	2.94	3.88			
110	111.7	1.52	0.97	69.6	1.69	1.39	46.1	1.87	1.90	36.8	1.98	2.25	27.7	2.19	2.70	21.0	2.44	3.20	17.3	2.68	3.53	14.3	2.94	3.88	12.4	3.23	4.07
120	121.7	1.52	0.97	75.8	1.69	1.39	50.2	1.87	1.90	40.1	1.98	2.26	30.2	2.19	2.70	22.9	2.44	3.20	18.8	2.66	3.57	15.5	2.91	3.96	13.4	3.17	4.19
130	131.6	1.51	0.97	82.1	1.69	1.39	54.4	1.87	1.90	43.4	1.97	2.26	32.7	2.19	2.70	24.8	2.44	3.20	20.3	2.64	3.61	16.7	2.88	4.03	14.4	3.12	4.30
140	141.5	1.51	0.97	88.3	1.69	1.39	58.5	1.87	1.90	46.7	1.97	2.26	35.2	2.19	2.70	26.6	2.42	3.24	21.8	2.63	3.64	17.9	2.85	4.08	15.5	3.12	4.31
150	151.4	1.52	0.97	94.5	1.69	1.40	62.6	1.87	1.91	50.0	1.98	2.26	37.6	2.18	2.72	28.5	2.42	3.23	23.3	2.62	3.66	19.2	2.86	4.07	16.5	3.08	4.39
160	161.3	1.52	0.97	100.7	1.69	1.40	66.7	1.87	1.91	53.3	1.98	2.26	40.1	2.18	2.72	30.4	2.43	3.23	24.8	2.61	3.68	20.4	2.84	4.11	17.6	3.08	4.39
170	171.1	1.52	0.97	106.8	1.69	1.40	70.8	1.87	1.91	56.5	1.97	2.28	42.6	2.19	2.72	32.2	2.41	3.26	26.3	2.60	3.70	21.7	2.85	4.10	18.6	3.05	4.46
180	180.9	1.52	0.98	113.0	1.69	1.40	74.9	1.87	1.91	59.8	1.97	2.27	45.0	2.18	2.73	34.1	2.42	3.25	27.9	2.61	3.68	22.9	2.83	4.14	19.6	3.02	4.52
190	190.6	1.52	0.98	119.1	1.69	1.40	79.0	1.87	1.91	63.1	1.98	2.27	47.5	2.18	2.73	35.9	2.41	3.27	29.4	2.61	3.69	24.1	2.81	4.17	20.7	3.03	4.51
200	200.4	1.52	0.98	125.3	1.69	1.40	83.0	1.87	1.92	66.3	1.97	2.28	49.9	2.18	2.74	37.8	2.41	3.27	30.9	2.60	3.71	25.4	2.82	4.15	21.7	3.00	4.57
220	220.1	1.52	0.98	137.6	1.69	1.41	91.2	1.87	1.92	72.9	1.97	2.28	54.9	2.18	2.74	41.5	2.41	3.28	33.9	2.59	3.73	27.9	2.82	4.17	23.8	2.99	4.61
240	239.8	1.52	0.98	150.0	1.69	1.41	99.4	1.87	1.93	79.5	1.98	2.28	59.8	2.18	2.75	45.3	2.41	3.28	37.0	2.60	3.72	30.4	2.81	4.18	25.9	2.97	4.64
260	259.4	1.52	0.98	162.3	1.69	1.41	107.6	1.87	1.93	86.0	1.97	2.28	64.8	2.18	2.74	49.0	2.41	3.29	40.0	2.59	3.75	32.9	2.81	4.20	28.0	2.96	4.67
280	279.0	1.52	0.98	174.6	1.70	1.41	115.8	1.87	1.93	92.5	1.97	2.29	69.7	2.18	2.75	52.7	2.40	3.30	43.0	2.58	3.76	35.3	2.79	4.24	30.2	2.97	4.65
300	298.5	1.52	0.98	186.9	1.70	1.41	123.9	1.87	1.93	99.1	1.98	2.29	74.6	2.18	2.75	56.4	2.40	3.30	46.1	2.59	3.75	37.8	2.79	4.24	32.3	2.97	4.67

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 4 of 14)

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 1.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	18.1	1.40	0.88	11.5	1.59	1.21	7.7	1.85	1.55																		
20	24.0	1.38	0.89	15.2	1.56	1.25	10.1	1.79	1.64	7.7	2.03	1.89															
25	30.0	1.38	0.89	19.0	1.56	1.25	12.5	1.75	1.69	9.5	1.97	1.97	7.8	2.19	2.16												
30	35.9	1.38	0.90	22.7	1.55	1.27	14.9	1.73	1.73	11.2	1.90	2.09	9.2	2.11	2.28												
35	41.8	1.38	0.90	26.4	1.54	1.28	17.3	1.71	1.75	13.0	1.88	2.12	10.5	2.02	2.44	8.3	2.36	2.64									
40	47.7	1.38	0.90	30.1	1.54	1.28	19.7	1.70	1.77	14.8	1.87	2.15	12.0	2.02	2.44	9.4	2.32	2.72									
45	53.6	1.38	0.90	33.9	1.54	1.28	22.1	1.69	1.78	16.6	1.86	2.17	13.4	1.99	2.50	10.5	2.28	2.78									
50	59.4	1.38	0.91	37.6	1.54	1.28	24.5	1.69	1.79	18.4	1.85	2.18	14.9	1.99	2.50	11.5	2.22	2.90	9.4	2.49	3.16						
55	65.3	1.38	0.91	41.3	1.54	1.28	26.9	1.69	1.80	20.2	1.84	2.19	16.3	1.97	2.54	12.6	2.20	2.94	10.3	2.47	3.20						
60	71.1	1.38	0.91	44.9	1.53	1.29	29.3	1.68	1.81	22.0	1.84	2.20	17.7	1.96	2.57	13.7	2.19	2.97	11.2	2.45	3.23						
65	76.9	1.38	0.91	48.6	1.54	1.29	31.7	1.68	1.81	23.7	1.82	2.24	19.2	1.97	2.56	14.8	2.18	2.99	12.0	2.40	3.34	9.8	2.76	3.55			
70	82.7	1.38	0.91	52.3	1.54	1.29	34.1	1.68	1.81	25.5	1.82	2.24	20.6	1.95	2.58	15.9	2.17	3.01	12.9	2.39	3.36	10.5	2.74	3.61			
75	88.4	1.38	0.91	55.9	1.53	1.30	36.5	1.68	1.82	27.3	1.82	2.24	22.1	1.96	2.57	17.0	2.16	3.03	13.8	2.39	3.38	11.1	2.67	3.76			
80	94.2	1.38	0.91	59.6	1.54	1.30	38.9	1.68	1.82	29.1	1.82	2.24	23.5	1.95	2.59	18.1	2.16	3.05	14.7	2.38	3.39	11.8	2.65	3.80	10.3	2.92	3.94
90	105.8	1.38	0.91	66.9	1.53	1.30	43.7	1.68	1.82	32.7	1.82	2.25	26.4	1.95	2.60	20.3	2.14	3.07	16.4	2.34	3.48	13.2	2.62	3.87	11.4	2.83	4.14
100	117.3	1.38	0.92	74.3	1.54	1.30	48.5	1.68	1.83	36.3	1.82	2.25	29.3	1.95	2.61	22.5	2.14	3.10	18.2	2.34	3.49	14.6	2.59	3.92	12.6	2.80	4.21
110	128.9	1.38	0.92	81.6	1.54	1.31	53.3	1.68	1.83	39.8	1.81	2.27	32.2	1.95	2.61	24.7	2.13	3.11	20.0	2.34	3.50	16.0	2.58	3.97	13.8	2.77	4.27
120	140.4	1.38	0.92	88.9	1.54	1.31	58.1	1.68	1.83	43.4	1.81	2.27	35.0	1.94	2.64	26.9	2.12	3.13	21.7	2.31	3.56	17.4	2.56	4.00	15.0	2.75	4.32
130	151.8	1.38	0.92	96.1	1.53	1.31	62.9	1.68	1.83	47.0	1.82	2.27	37.9	1.94	2.64	29.1	2.12	3.14	23.5	2.31	3.56	18.8	2.55	4.04	16.2	2.74	4.36
140	163.2	1.38	0.92	103.4	1.54	1.31	67.6	1.68	1.84	50.5	1.81	2.28	40.8	1.94	2.64	31.3	2.12	3.14	25.3	2.31	3.56	20.2	2.54	4.06	17.4	2.72	4.39
150	174.6	1.38	0.92	110.6	1.53	1.31	72.4	1.68	1.83	54.1	1.81	2.28	43.7	1.94	2.64	33.5	2.12	3.15	27.0	2.30	3.60	21.6	2.53	4.08	18.6	2.71	4.42
160	186.0	1.38	0.92	117.8	1.53	1.32	77.1	1.68	1.84	57.6	1.81	2.29	46.5	1.93	2.65	35.7	2.12	3.16	28.8	2.30	3.60	22.9	2.50	4.16	19.8	2.70	4.45
170	197.3	1.39	0.92	125.0	1.54	1.32	81.9	1.68	1.84	61.2	1.81	2.28	49.4	1.94	2.65	37.9	2.12	3.16	30.6	2.30	3.59	24.3	2.50	4.17	21.0	2.69	4.47
180	208.5	1.38	0.93	132.2	1.54	1.32	86.6	1.68	1.84	64.7	1.81	2.29	52.2	1.93	2.66	40.1	2.12	3.16	32.3	2.29	3.62	25.7	2.49	4.18	22.2	2.69	4.49
190	219.8	1.39	0.93	139.3	1.54	1.32	91.3	1.68	1.84	68.2	1.81	2.29	55.1	1.94	2.65	42.3	2.12	3.16	34.1	2.30	3.62	27.1	2.49	4.19	23.4	2.68	4.51
200	231.0	1.39	0.93	146.5	1.54	1.32	96.0	1.68	1.84	71.8	1.82	2.29	57.9	1.93	2.66	44.5	2.12	3.17	35.8	2.29	3.64	28.5	2.49	4.20	24.6	2.68	4.52
220	253.7	1.39	0.93	160.9	1.54	1.32	105.5	1.68	1.84	78.9	1.82	2.29	63.7	1.94	2.66	48.9	2.12	3.17	39.4	2.29	3.63	31.3	2.48	4.22	27.0	2.67	4.55
240	276.3	1.39	0.93	175.3	1.54	1.33	115.0	1.69	1.84	85.9	1.81	2.30	69.4	1.94	2.66	53.3	2.11	3.18	42.9	2.29	3.65	34.1	2.48	4.23	29.4	2.66	4.57
260	298.9	1.39	0.93	189.7	1.54	1.33	124.4	1.68	1.85	93.0	1.81	2.30	75.1	1.93	2.67	57.6	2.11	3.19	46.5	2.29	3.64	36.9	2.48	4.24	31.8	2.65	4.59
280	321.3	1.39	0.93	204.0	1.54	1.33	133.9	1.69	1.85	100.1	1.82	2.30	80.8	1.93	2.67	62.0	2.11	3.19	50.0	2.29	3.65	39.7	2.47	4.25	34.2	2.65	4.61
300	343.7	1.39	0.93	218.2	1.54	1.33	143.3	1.69	1.85	107.1	1.81	2.30	86.5	1.94	2.67	66.4	2.11	3.19	53.5	2.28	3.66	42.5	2.47	4.26	36.6	2.65	4.62

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 5 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 1.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	20.1	1.29	0.86	13.2	1.43	1.17	8.9	1.65	1.51																		
20	26.8	1.29	0.86	17.5	1.42	1.19	11.7	1.60	1.58	8.1	1.86	1.95	6.7	2.09	2.10												
25	33.4	1.28	0.86	21.8	1.41	1.21	14.5	1.57	1.63	9.9	1.78	2.10	8.1	1.95	2.34												
30	40.0	1.28	0.87	26.2	1.42	1.20	17.4	1.57	1.63	11.8	1.75	2.15	9.6	1.90	2.43	8.0	2.13	2.60									
35	46.5	1.28	0.87	30.5	1.41	1.21	20.2	1.56	1.65	13.7	1.74	2.18	11.1	1.86	2.50	9.2	2.06	2.72									
40	53.1	1.28	0.87	34.8	1.41	1.21	23.0	1.55	1.67	15.6	1.73	2.20	12.6	1.84	2.56	10.4	2.02	2.82	8.2	2.38	3.03						
45	59.6	1.28	0.88	39.0	1.40	1.22	25.9	1.55	1.66	17.5	1.72	2.22	14.2	1.85	2.55	11.7	2.02	2.82	9.1	2.31	3.16						
50	66.1	1.28	0.88	43.3	1.41	1.22	28.7	1.55	1.67	19.4	1.71	2.24	15.7	1.83	2.58	12.9	1.99	2.89	10.0	2.26	3.27						
55	72.6	1.28	0.88	47.6	1.41	1.22	31.5	1.55	1.68	21.3	1.71	2.25	17.2	1.82	2.61	14.2	1.99	2.89	10.9	2.22	3.36	9.3	2.47	3.54			
60	79.0	1.28	0.88	51.8	1.41	1.22	34.3	1.54	1.69	23.2	1.70	2.25	18.8	1.82	2.60	15.4	1.97	2.94	11.9	2.22	3.36	10.1	2.45	3.59			
65	85.5	1.28	0.88	56.0	1.40	1.23	37.1	1.54	1.69	25.1	1.70	2.26	20.3	1.82	2.62	16.6	1.95	2.98	12.8	2.19	3.43	10.8	2.39	3.73			
70	91.9	1.28	0.88	60.3	1.41	1.22	39.9	1.54	1.69	27.0	1.70	2.26	21.8	1.81	2.64	17.9	1.96	2.96	13.8	2.20	3.42	11.6	2.38	3.76	9.8	2.62	4.03
75	98.2	1.28	0.89	64.5	1.41	1.23	42.7	1.54	1.69	28.9	1.70	2.27	23.3	1.80	2.66	19.1	1.95	3.00	14.7	2.18	3.48	12.4	2.37	3.79	10.5	2.62	4.04
80	104.6	1.28	0.89	68.7	1.41	1.23	45.5	1.54	1.70	30.8	1.70	2.27	24.9	1.81	2.64	20.4	1.95	2.98	15.7	2.18	3.46	13.2	2.36	3.81	11.1	2.58	4.15
90	117.5	1.28	0.89	77.1	1.41	1.23	51.1	1.54	1.70	34.6	1.70	2.28	27.9	1.80	2.67	22.9	1.95	3.00	17.6	2.17	3.50	14.7	2.31	3.93	12.4	2.54	4.24
100	130.3	1.28	0.89	85.6	1.41	1.23	56.7	1.54	1.70	38.3	1.69	2.30	31.0	1.80	2.66	25.4	1.94	3.02	19.5	2.16	3.53	16.3	2.30	3.96	13.7	2.51	4.32
110	143.0	1.28	0.89	94.0	1.41	1.24	62.3	1.54	1.71	42.1	1.69	2.30	34.0	1.79	2.68	27.9	1.94	3.03	21.4	2.15	3.56	17.9	2.30	3.98	15.0	2.49	4.38
120	155.8	1.28	0.89	102.4	1.41	1.24	67.9	1.54	1.71	45.9	1.69	2.30	37.1	1.80	2.68	30.4	1.94	3.03	23.3	2.14	3.57	19.5	2.29	3.99	16.3	2.47	4.43
130	168.4	1.28	0.90	110.7	1.41	1.24	73.4	1.54	1.71	49.7	1.69	2.30	40.1	1.79	2.69	32.9	1.94	3.04	25.2	2.14	3.59	21.1	2.29	4.01	17.6	2.45	4.48
140	181.0	1.28	0.90	119.1	1.41	1.24	79.0	1.54	1.71	53.4	1.69	2.31	43.2	1.80	2.68	35.3	1.93	3.07	27.1	2.14	3.60	22.7	2.29	4.02	18.9	2.44	4.51
150	193.6	1.28	0.90	127.4	1.41	1.24	84.5	1.54	1.72	57.2	1.69	2.31	46.2	1.79	2.70	37.8	1.93	3.07	29.0	2.13	3.61	24.2	2.27	4.07	20.2	2.43	4.54
160	206.2	1.28	0.90	135.7	1.41	1.24	90.0	1.54	1.72	60.9	1.69	2.32	49.3	1.80	2.69	40.3	1.93	3.07	30.9	2.13	3.62	25.8	2.27	4.08	21.6	2.45	4.51
170	218.6	1.28	0.90	144.0	1.41	1.24	95.6	1.54	1.72	64.7	1.69	2.31	52.3	1.80	2.69	42.8	1.93	3.07	32.8	2.13	3.62	27.4	2.27	4.08	22.9	2.44	4.53
180	231.1	1.28	0.90	152.2	1.41	1.25	101.0	1.54	1.72	68.4	1.69	2.32	55.3	1.80	2.70	45.3	1.93	3.07	34.7	2.13	3.63	29.0	2.27	4.08	24.2	2.43	4.56
190	243.5	1.28	0.90	160.4	1.41	1.25	106.5	1.54	1.72	72.1	1.69	2.32	58.3	1.80	2.71	47.7	1.92	3.08	36.5	2.12	3.66	30.6	2.27	4.08	25.5	2.42	4.58
200	255.8	1.28	0.91	168.6	1.41	1.25	112.0	1.54	1.72	75.9	1.69	2.32	61.3	1.79	2.71	50.2	1.93	3.08	38.4	2.12	3.66	32.1	2.26	4.12	26.8	2.42	4.60
220	280.9	1.28	0.91	185.2	1.41	1.25	123.0	1.54	1.73	83.4	1.69	2.32	67.4	1.80	2.71	55.2	1.93	3.08	42.2	2.12	3.67	35.3	2.26	4.12	29.5	2.42	4.58
240	305.8	1.28	0.91	201.7	1.41	1.25	134.1	1.54	1.73	90.9	1.69	2.32	73.5	1.80	2.71	60.1	1.92	3.09	46.0	2.12	3.67	38.5	2.26	4.12	32.1	2.41	4.62
260	330.7	1.28	0.91	218.2	1.41	1.26	145.1	1.54	1.73	98.3	1.69	2.33	79.5	1.80	2.72	65.1	1.93	3.09	49.8	2.12	3.68	41.7	2.26	4.12	34.7	2.41	4.64
280	355.5	1.28	0.91	234.7	1.41	1.26	156.0	1.54	1.73	105.8	1.69	2.33	85.5	1.79	2.72	70.0	1.93	3.10	53.6	2.12	3.68	44.8	2.25	4.14	37.4	2.41	4.63
300	380.2	1.28	0.91	251.1	1.41	1.26	167.0	1.54	1.73	113.2	1.69	2.33	91.6	1.80	2.72	74.9	1.92	3.11	57.4	2.12	3.68	48.0	2.25	4.14	40.0	2.41	4.65

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 6 of 14)

4-26487 5-88

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**

Grade 1.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	21.8	1.21	0.84	14.2	1.33	1.17	10.0	1.50	1.48	6.9	1.74	1.84															
20	29.0	1.20	0.85	18.9	1.33	1.18	13.2	1.46	1.53	9.0	1.66	1.98	7.6	1.83	2.12												
25	36.2	1.20	0.85	23.5	1.32	1.20	16.4	1.45	1.56	11.2	1.64	2.01	9.3	1.75	2.27	7.6	1.93	2.51									
30	43.4	1.21	0.85	28.2	1.32	1.20	19.6	1.44	1.58	13.3	1.60	2.08	11.1	1.72	2.32	9.0	1.88	2.62									
35	50.5	1.20	0.85	32.8	1.31	1.21	22.8	1.43	1.59	15.5	1.60	2.09	12.8	1.68	2.40	10.4	1.84	2.70	8.2	2.11	2.98						
40	57.6	1.20	0.85	37.4	1.31	1.21	26.0	1.43	1.60	17.6	1.58	2.13	14.6	1.68	2.42	11.8	1.81	2.77	9.3	2.08	3.06						
45	64.6	1.20	0.86	42.0	1.31	1.21	29.2	1.43	1.61	19.8	1.58	2.13	16.4	1.68	2.43	13.2	1.79	2.82	10.3	2.01	3.21	8.6	2.26	3.41			
50	71.6	1.20	0.86	46.6	1.31	1.21	32.4	1.43	1.61	21.9	1.57	2.16	18.2	1.67	2.44	14.7	1.80	2.80	11.4	2.00	3.25	9.5	2.24	3.48			
55	78.6	1.20	0.86	51.2	1.31	1.22	35.6	1.43	1.61	24.1	1.58	2.15	19.9	1.66	2.48	16.1	1.79	2.83	12.5	1.99	3.28	10.3	2.17	3.64	8.6	2.51	3.77
60	85.6	1.20	0.87	55.8	1.31	1.22	38.8	1.43	1.61	26.2	1.57	2.17	21.7	1.66	2.48	17.5	1.78	2.86	13.6	1.98	3.31	11.2	2.16	3.67	9.2	2.41	4.00
65	92.6	1.20	0.87	60.3	1.31	1.22	41.9	1.42	1.62	28.4	1.57	2.16	23.5	1.66	2.48	18.9	1.77	2.88	14.7	1.97	3.33	12.1	2.15	3.70	9.9	2.38	4.08
70	99.5	1.20	0.87	64.9	1.32	1.22	45.1	1.42	1.62	30.5	1.57	2.18	25.2	1.65	2.50	20.3	1.76	2.90	15.8	1.96	3.35	13.0	2.14	3.73	10.6	2.35	4.15
75	106.4	1.20	0.87	69.4	1.31	1.22	48.2	1.42	1.63	32.7	1.57	2.17	27.0	1.65	2.50	21.8	1.78	2.88	16.9	1.96	3.36	13.9	2.13	3.75	11.4	2.37	4.11
80	113.3	1.20	0.87	73.9	1.31	1.22	51.4	1.43	1.62	34.8	1.57	2.18	28.8	1.66	2.50	23.2	1.77	2.90	17.9	1.94	3.43	14.8	2.13	3.77	12.1	2.35	4.17
90	127.2	1.20	0.87	83.0	1.31	1.23	57.7	1.42	1.63	39.1	1.57	2.18	32.3	1.65	2.52	26.0	1.76	2.93	20.1	1.93	3.45	16.6	2.12	3.81	13.5	2.31	4.28
100	141.0	1.20	0.87	92.1	1.32	1.23	64.0	1.42	1.64	43.4	1.57	2.18	35.8	1.64	2.53	28.9	1.76	2.92	22.3	1.93	3.46	18.4	2.11	3.83	14.9	2.28	4.37
110	154.9	1.21	0.87	101.2	1.32	1.23	70.4	1.43	1.63	47.7	1.57	2.19	39.4	1.65	2.52	31.7	1.76	2.94	24.5	1.92	3.47	20.1	2.08	3.91	16.4	2.29	4.36
120	168.6	1.20	0.88	110.2	1.32	1.23	76.6	1.42	1.64	51.9	1.57	2.20	42.9	1.64	2.53	34.6	1.76	2.93	26.7	1.92	3.48	21.9	2.08	3.93	17.8	2.26	4.43
130	182.3	1.21	0.88	119.2	1.32	1.23	82.9	1.42	1.64	56.2	1.57	2.20	46.4	1.64	2.54	37.4	1.76	2.95	28.9	1.92	3.49	23.7	2.07	3.93	19.2	2.25	4.48
140	196.0	1.21	0.88	128.1	1.32	1.23	89.2	1.43	1.64	60.4	1.57	2.21	49.9	1.64	2.55	40.2	1.75	2.96	31.1	1.92	3.49	25.5	2.07	3.94	20.7	2.25	4.47
150	209.6	1.21	0.88	137.1	1.32	1.23	95.4	1.42	1.64	64.7	1.57	2.20	53.4	1.64	2.55	43.1	1.76	2.95	33.3	1.92	3.49	27.3	2.07	3.95	22.1	2.24	4.51
160	223.1	1.21	0.88	146.0	1.32	1.24	101.6	1.42	1.65	68.9	1.57	2.21	56.9	1.64	2.55	45.9	1.76	2.96	35.4	1.91	3.52	29.1	2.07	3.95	23.6	2.25	4.49
170	236.6	1.21	0.88	154.9	1.32	1.24	107.9	1.43	1.64	73.1	1.57	2.21	60.4	1.64	2.55	48.7	1.76	2.96	37.6	1.91	3.52	30.9	2.07	3.95	25.0	2.24	4.53
180	250.0	1.21	0.89	163.7	1.32	1.24	114.0	1.43	1.65	77.4	1.57	2.21	63.9	1.64	2.55	51.5	1.75	2.97	39.8	1.92	3.52	32.6	2.06	3.99	26.4	2.23	4.56
190	263.4	1.21	0.89	172.6	1.32	1.24	120.2	1.43	1.65	81.6	1.57	2.21	67.4	1.64	2.55	54.3	1.75	2.97	42.0	1.92	3.52	34.4	2.06	3.99	27.9	2.23	4.54
200	276.7	1.21	0.89	181.4	1.32	1.24	126.4	1.43	1.65	85.7	1.57	2.22	70.8	1.64	2.56	57.1	1.75	2.98	44.1	1.91	3.54	36.2	2.06	3.99	29.3	2.23	4.57
220	303.8	1.21	0.89	199.2	1.32	1.24	138.8	1.43	1.65	94.2	1.57	2.22	77.8	1.64	2.57	62.8	1.76	2.97	48.5	1.91	3.53	39.8	2.07	3.99	32.2	2.22	4.58
240	330.8	1.21	0.89	217.0	1.32	1.24	151.2	1.43	1.66	102.7	1.57	2.22	84.8	1.64	2.57	68.4	1.75	2.98	52.9	1.92	3.53	43.3	2.06	4.02	35.1	2.22	4.58
260	357.7	1.21	0.89	234.7	1.32	1.25	163.6	1.43	1.66	111.1	1.57	2.22	91.8	1.64	2.57	74.1	1.76	2.98	57.2	1.91	3.54	46.9	2.06	4.01	38.0	2.22	4.59
280	384.5	1.21	0.89	252.3	1.32	1.25	176.0	1.43	1.66	119.5	1.57	2.23	98.7	1.64	2.58	79.7	1.76	2.98	61.6	1.92	3.54	50.5	2.06	4.01	40.9	2.22	4.59
300	411.2	1.21	0.90	269.9	1.32	1.25	188.3	1.43	1.66	127.9	1.57	2.23	105.7	1.64	2.57	85.3	1.76	2.99	65.9	1.91	3.55	54.0	2.06	4.03	43.7	2.21	4.62

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 7 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 2.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	24.7	1.14	0.79	15.0	1.25	1.18	11.0	1.40	1.43	7.8	1.56	1.81															
20	32.8	1.14	0.79	20.0	1.25	1.18	14.5	1.37	1.49	10.3	1.53	1.88	7.5	1.71	2.29	6.3	1.91	2.44									
25	41.0	1.14	0.79	24.9	1.24	1.20	18.1	1.37	1.50	12.7	1.48	1.96	9.3	1.68	2.36	7.7	1.82	2.62									
30	49.0	1.14	0.80	29.8	1.24	1.20	21.6	1.35	1.52	15.2	1.48	1.98	11.0	1.63	2.47	9.1	1.77	2.76	7.6	1.97	2.95						
35	57.1	1.14	0.80	34.7	1.24	1.21	25.1	1.35	1.54	17.7	1.47	1.99	12.8	1.62	2.50	10.5	1.73	2.86	8.8	1.94	3.03						
40	65.1	1.14	0.80	39.6	1.24	1.21	28.7	1.35	1.53	20.2	1.47	2.00	14.6	1.62	2.51	12.0	1.73	2.86	9.9	1.88	3.18	8.2	2.13	3.38			
45	73.1	1.14	0.80	44.5	1.24	1.21	32.2	1.35	1.54	22.6	1.46	2.03	16.4	1.61	2.52	13.5	1.73	2.86	11.1	1.87	3.21	9.1	2.08	3.52			
50	81.0	1.14	0.81	49.3	1.24	1.22	35.7	1.35	1.55	25.1	1.46	2.03	18.1	1.59	2.57	14.9	1.71	2.92	12.3	1.86	3.24	10.0	2.03	3.64	8.6	2.29	3.76
55	88.9	1.14	0.81	54.2	1.24	1.21	39.2	1.34	1.55	27.6	1.46	2.03	19.9	1.60	2.57	16.4	1.71	2.91	13.5	1.85	3.26	11.0	2.03	3.65	9.3	2.21	3.96
60	96.8	1.14	0.81	59.0	1.24	1.22	42.7	1.34	1.55	30.0	1.45	2.05	21.7	1.60	2.57	17.8	1.69	2.95	14.7	1.85	3.28	11.9	2.00	3.74	10.1	2.19	4.01
65	104.6	1.14	0.81	63.8	1.24	1.22	46.2	1.35	1.55	32.5	1.46	2.04	23.4	1.58	2.60	19.3	1.70	2.94	15.8	1.82	3.36	12.9	2.00	3.73	10.9	2.18	4.06
70	112.4	1.14	0.81	68.6	1.24	1.22	49.7	1.35	1.56	34.9	1.45	2.05	25.2	1.59	2.60	20.7	1.69	2.98	17.0	1.82	3.36	13.8	1.98	3.81	11.7	2.16	4.10
75	120.2	1.14	0.81	73.4	1.24	1.22	53.1	1.34	1.56	37.3	1.45	2.06	27.0	1.59	2.60	22.2	1.69	2.96	18.2	1.82	3.37	14.8	1.98	3.79	12.5	2.15	4.14
80	127.9	1.14	0.82	78.1	1.24	1.23	56.6	1.35	1.56	39.8	1.45	2.06	28.7	1.58	2.62	23.6	1.69	2.99	19.4	1.82	3.37	15.8	1.99	3.78	13.3	2.14	4.17
90	143.6	1.14	0.82	87.8	1.24	1.23	63.5	1.34	1.57	44.7	1.45	2.06	32.3	1.59	2.61	26.5	1.68	3.00	21.8	1.82	3.38	17.7	1.97	3.83	14.9	2.12	4.22
100	159.2	1.14	0.82	97.4	1.24	1.23	70.5	1.34	1.57	49.6	1.45	2.07	35.8	1.58	2.63	29.4	1.68	3.01	24.1	1.80	3.43	19.6	1.96	3.87	16.5	2.11	4.26
110	174.8	1.14	0.82	106.9	1.24	1.23	77.4	1.34	1.57	54.5	1.45	2.07	39.3	1.58	2.64	32.3	1.68	3.02	26.5	1.80	3.43	21.5	1.95	3.90	18.1	2.10	4.30
120	190.3	1.14	0.82	116.5	1.24	1.23	84.3	1.34	1.58	59.4	1.45	2.07	42.8	1.58	2.65	35.2	1.68	3.02	28.9	1.80	3.43	23.4	1.94	3.92	19.7	2.09	4.33
130	205.7	1.14	0.82	126.0	1.24	1.23	91.2	1.34	1.58	64.2	1.45	2.08	46.4	1.58	2.64	38.1	1.68	3.03	31.3	1.80	3.43	25.4	1.95	3.90	21.3	2.09	4.35
140	221.0	1.14	0.82	135.4	1.24	1.24	98.0	1.34	1.58	69.1	1.45	2.08	49.9	1.58	2.64	41.0	1.68	3.03	33.6	1.80	3.46	27.3	1.95	3.92	22.9	2.08	4.37
150	236.3	1.14	0.83	144.9	1.25	1.24	104.9	1.34	1.58	73.9	1.45	2.08	53.4	1.58	2.65	43.9	1.68	3.03	36.0	1.80	3.45	29.2	1.95	3.93	24.5	2.08	4.38
160	251.5	1.14	0.83	154.3	1.25	1.24	111.7	1.34	1.59	78.7	1.45	2.09	56.9	1.58	2.65	46.7	1.67	3.05	38.3	1.79	3.47	31.1	1.94	3.94	26.1	2.08	4.40
170	266.6	1.14	0.83	163.7	1.25	1.24	118.5	1.34	1.59	83.6	1.45	2.08	60.3	1.58	2.66	49.6	1.68	3.05	40.7	1.80	3.46	33.0	1.94	3.95	27.7	2.07	4.41
180	281.7	1.14	0.83	173.0	1.25	1.24	125.2	1.34	1.59	88.4	1.45	2.09	63.8	1.58	2.66	52.5	1.68	3.04	43.0	1.79	3.48	34.9	1.94	3.96	29.3	2.07	4.41
190	296.7	1.14	0.83	182.3	1.25	1.24	132.0	1.34	1.59	93.2	1.45	2.09	67.3	1.58	2.66	55.3	1.68	3.06	45.4	1.80	3.47	36.8	1.94	3.97	30.8	2.06	4.46
200	311.7	1.14	0.83	191.6	1.25	1.24	138.7	1.34	1.60	97.9	1.45	2.10	70.7	1.58	2.67	58.2	1.68	3.05	47.7	1.79	3.49	38.7	1.94	3.97	32.4	2.06	4.47
220	342.1	1.14	0.83	210.4	1.25	1.25	152.4	1.35	1.60	107.6	1.45	2.10	77.7	1.58	2.67	63.9	1.68	3.06	52.5	1.80	3.47	42.5	1.93	3.99	35.6	2.06	4.48
240	372.4	1.14	0.84	229.2	1.25	1.25	165.9	1.34	1.60	117.2	1.45	2.10	84.7	1.58	2.67	69.7	1.68	3.06	57.2	1.80	3.48	46.4	1.94	3.97	38.8	2.06	4.49
260	402.5	1.14	0.84	247.9	1.25	1.25	179.5	1.34	1.60	126.8	1.45	2.10	91.7	1.58	2.67	75.4	1.68	3.07	61.9	1.80	3.49	50.2	1.94	3.99	42.0	2.06	4.49
280	432.6	1.14	0.84	266.5	1.25	1.25	193.0	1.34	1.61	136.4	1.45	2.10	98.6	1.58	2.68	81.1	1.68	3.07	66.6	1.80	3.49	54.0	1.94	3.99	45.2	2.06	4.49
300	462.5	1.14	0.84	285.1	1.25	1.25	206.5	1.35	1.61	146.0	1.46	2.10	105.5	1.58	2.69	86.8	1.68	3.07	71.2	1.79	3.51	57.8	1.94	4.00	48.4	2.06	4.50

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 8 of 14)

4-26467 5-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 3.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	28.1	0.98	0.80	19.2	1.05	1.10	13.4	1.15	1.44	10.3	1.24	1.74	7.6	1.37	2.12	5.8	1.56	2.44									
20	37.4	0.98	0.80	25.6	1.05	1.10	17.8	1.14	1.46	13.7	1.23	1.76	10.0	1.33	2.22	7.6	1.50	2.59	6.8	1.58	2.74						
25	46.7	0.99	0.80	31.9	1.05	1.11	22.2	1.14	1.47	17.0	1.21	1.80	12.5	1.33	2.23	9.4	1.46	2.69	8.4	1.54	2.85	6.9	1.68	3.18			
30	55.9	0.99	0.81	38.2	1.05	1.11	26.6	1.14	1.47	20.3	1.20	1.82	14.9	1.31	2.27	11.2	1.44	2.75	9.9	1.48	3.02	8.2	1.64	3.28	6.7	1.88	3.50
35	65.0	0.99	0.81	44.4	1.04	1.12	31.0	1.14	1.47	23.7	1.21	1.81	17.3	1.30	2.30	13.0	1.43	2.80	11.5	1.47	3.07	9.5	1.62	3.36	7.7	1.82	3.68
40	74.1	0.99	0.81	50.6	1.04	1.12	35.3	1.14	1.48	27.0	1.20	1.83	19.7	1.29	2.33	14.8	1.42	2.83	13.1	1.46	3.10	10.8	1.60	3.42	8.7	1.78	3.82
45	83.2	0.99	0.81	56.8	1.04	1.13	39.7	1.14	1.48	30.3	1.20	1.84	22.1	1.29	2.34	16.6	1.41	2.85	14.7	1.45	3.12	12.1	1.59	3.46	9.7	1.75	3.92
50	92.2	0.99	0.81	63.0	1.04	1.13	44.0	1.14	1.48	33.6	1.20	1.84	24.6	1.30	2.32	18.4	1.40	2.87	16.3	1.45	3.14	13.4	1.58	3.50	10.7	1.72	4.01
55	101.1	0.99	0.82	69.1	1.04	1.13	48.3	1.14	1.49	36.9	1.20	1.84	27.0	1.30	2.34	20.2	1.40	2.88	17.9	1.45	3.15	14.7	1.57	3.53	11.7	1.70	4.09
60	110.1	0.99	0.82	75.3	1.05	1.13	52.6	1.14	1.49	40.2	1.20	1.85	29.4	1.29	2.34	22.0	1.40	2.89	19.5	1.45	3.16	16.0	1.57	3.55	12.7	1.69	4.15
65	118.9	0.99	0.82	81.4	1.05	1.13	56.9	1.14	1.49	43.4	1.20	1.86	31.8	1.29	2.35	23.8	1.40	2.90	21.1	1.45	3.16	17.3	1.57	3.56	13.8	1.70	4.11
70	127.8	0.99	0.82	87.4	1.04	1.14	61.1	1.14	1.50	46.7	1.20	1.86	34.2	1.29	2.35	25.6	1.40	2.90	22.7	1.45	3.17	18.5	1.55	3.63	14.8	1.69	4.16
75	136.6	0.99	0.82	93.5	1.05	1.14	65.4	1.14	1.50	49.9	1.20	1.87	36.6	1.29	2.35	27.4	1.40	2.91	24.2	1.44	3.21	19.8	1.55	3.64	15.8	1.68	4.20
80	145.3	0.99	0.83	99.5	1.05	1.14	69.6	1.14	1.50	53.1	1.20	1.87	38.9	1.29	2.37	29.2	1.40	2.91	25.8	1.44	3.21	21.1	1.55	3.64	16.9	1.69	4.16
90	163.1	0.99	0.83	111.7	1.05	1.14	78.2	1.14	1.50	59.7	1.20	1.87	43.7	1.29	2.38	32.7	1.39	2.94	29.0	1.44	3.21	23.7	1.54	3.66	18.9	1.67	4.23
100	180.8	0.99	0.83	123.8	1.05	1.15	86.7	1.14	1.51	66.2	1.20	1.88	48.5	1.29	2.38	36.3	1.39	2.95	32.2	1.44	3.21	26.3	1.54	3.67	21.0	1.67	4.23
110	198.3	0.99	0.83	135.9	1.05	1.15	95.2	1.14	1.51	72.7	1.20	1.88	53.3	1.29	2.38	39.9	1.39	2.95	35.4	1.44	3.21	28.9	1.54	3.67	23.1	1.68	4.22
120	215.8	0.99	0.83	148.0	1.05	1.15	103.7	1.14	1.51	79.2	1.20	1.88	58.1	1.29	2.38	43.5	1.39	2.95	38.5	1.43	3.23	31.5	1.54	3.68	25.1	1.67	4.27
130	233.3	0.99	0.83	160.0	1.05	1.15	112.1	1.14	1.51	85.7	1.20	1.88	62.8	1.29	2.39	47.0	1.39	2.96	41.7	1.44	3.23	34.1	1.54	3.68	27.2	1.67	4.26
140	250.6	0.99	0.84	171.9	1.05	1.15	120.5	1.14	1.52	92.1	1.20	1.89	67.6	1.29	2.38	50.6	1.39	2.96	44.8	1.43	3.24	36.7	1.54	3.68	29.3	1.67	4.25
150	267.8	0.99	0.84	183.8	1.05	1.16	128.9	1.14	1.52	98.5	1.20	1.89	72.3	1.29	2.39	54.1	1.39	2.97	48.0	1.44	3.24	39.3	1.55	3.68	31.3	1.67	4.28
160	285.0	0.99	0.84	195.7	1.05	1.16	137.2	1.14	1.52	104.9	1.20	1.89	77.0	1.29	2.39	57.7	1.39	2.96	51.1	1.44	3.25	41.8	1.54	3.70	33.4	1.67	4.27
170	302.0	0.99	0.84	207.5	1.05	1.16	145.5	1.14	1.52	111.3	1.20	1.89	81.7	1.29	2.40	61.2	1.39	2.97	54.3	1.44	3.24	44.4	1.54	3.70	35.4	1.67	4.29
180	319.0	0.99	0.84	219.2	1.05	1.16	153.8	1.14	1.53	117.7	1.20	1.89	86.4	1.29	2.40	64.7	1.39	2.98	57.4	1.44	3.25	47.0	1.55	3.69	37.5	1.67	4.28
190	335.9	0.99	0.85	231.0	1.05	1.16	162.1	1.14	1.53	124.0	1.20	1.90	91.1	1.30	2.40	68.2	1.39	2.98	60.5	1.44	3.25	49.5	1.54	3.71	39.5	1.67	4.30
200	352.7	0.99	0.85	242.6	1.05	1.16	170.3	1.14	1.53	130.3	1.20	1.90	95.7	1.29	2.40	71.7	1.39	2.99	63.6	1.44	3.26	52.1	1.55	3.70	41.6	1.67	4.28
220	387.1	0.99	0.85	266.3	1.05	1.17	187.0	1.14	1.53	143.1	1.20	1.90	105.1	1.29	2.41	78.8	1.39	2.99	69.9	1.44	3.26	57.2	1.54	3.71	45.7	1.67	4.29
240	421.2	0.99	0.85	289.9	1.05	1.17	203.6	1.14	1.53	155.9	1.20	1.90	114.5	1.29	2.41	85.9	1.39	2.99	76.2	1.44	3.26	62.3	1.54	3.72	49.8	1.67	4.30
260	455.2	0.99	0.85	313.4	1.05	1.17	220.2	1.14	1.54	168.6	1.20	1.91	123.9	1.30	2.41	92.9	1.39	2.99	82.4	1.44	3.27	67.5	1.55	3.72	53.9	1.67	4.31
280	489.0	0.99	0.85	336.9	1.05	1.17	236.7	1.14	1.54	181.3	1.20	1.91	133.3	1.30	2.41	99.9	1.39	3.00	88.6	1.44	3.27	72.6	1.55	3.72	58.0	1.67	4.31
300	522.6	0.99	0.86	360.2	1.05	1.17	253.2	1.15	1.54	193.9	1.20	1.91	142.6	1.30	2.42	106.9	1.39	3.00	94.9	1.44	3.27	77.7	1.55	3.73	62.0	1.67	4.33

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 9 of 14)

4-28467 5-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 4.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	33.1	0.87	0.77	23.6	0.93	1.01	16.3	1.00	1.36	12.1	1.08	1.69	9.2	1.15	2.08	7.4	1.27	2.34	5.7	1.43	2.69						
20	44.0	0.87	0.77	31.4	0.93	1.01	21.7	1.00	1.37	16.1	1.08	1.70	12.3	1.16	2.08	9.7	1.23	2.48	7.4	1.35	2.94	6.4	1.47	3.12			
25	54.9	0.87	0.77	39.1	0.93	1.02	27.1	1.00	1.37	20.1	1.08	1.71	15.3	1.15	2.11	12.1	1.22	2.50	9.2	1.33	3.01	7.9	1.43	3.26	6.5	1.56	3.62
30	65.7	0.87	0.78	46.8	0.93	1.02	32.4	0.99	1.38	24.0	1.07	1.73	18.3	1.14	2.13	14.4	1.20	2.57	11.0	1.32	3.05	9.3	1.38	3.46	7.7	1.52	3.78
35	76.4	0.87	0.78	54.5	0.93	1.02	37.7	0.99	1.39	27.9	1.07	1.74	21.3	1.14	2.14	16.8	1.20	2.57	12.7	1.30	3.14	10.9	1.39	3.42	8.9	1.49	3.90
40	87.1	0.87	0.78	62.1	0.93	1.03	43.0	0.99	1.39	31.9	1.07	1.74	24.3	1.14	2.15	19.2	1.21	2.56	14.5	1.30	3.15	12.4	1.38	3.47	10.2	1.50	3.87
45	97.7	0.87	0.78	69.7	0.93	1.03	48.3	0.99	1.39	35.8	1.07	1.74	27.2	1.13	2.17	21.5	1.20	2.59	16.3	1.30	3.16	13.9	1.37	3.51	11.4	1.48	3.95
50	108.3	0.87	0.78	77.3	0.93	1.03	53.5	0.99	1.40	39.7	1.07	1.75	30.2	1.13	2.17	23.9	1.20	2.58	18.1	1.30	3.16	15.4	1.36	3.54	12.6	1.46	4.01
55	118.8	0.87	0.78	84.7	0.93	1.04	58.7	0.99	1.40	43.6	1.07	1.75	33.2	1.13	2.17	26.2	1.20	2.60	19.8	1.29	3.21	16.9	1.36	3.56	13.8	1.45	4.06
60	129.2	0.87	0.79	92.2	0.93	1.04	63.9	0.99	1.40	47.4	1.07	1.76	36.1	1.13	2.18	28.5	1.19	2.62	21.6	1.29	3.20	18.4	1.36	3.57	15.1	1.46	4.02
65	139.6	0.87	0.79	99.6	0.93	1.04	69.1	0.99	1.41	51.3	1.07	1.76	39.0	1.13	2.19	30.9	1.20	2.61	23.4	1.29	3.19	19.9	1.35	3.58	16.3	1.46	4.06
70	149.9	0.88	0.79	107.0	0.93	1.04	74.2	0.99	1.41	55.1	1.07	1.77	42.0	1.13	2.19	33.2	1.20	2.62	25.1	1.28	3.23	21.4	1.35	3.59	17.5	1.45	4.09
75	160.2	0.88	0.79	114.3	0.93	1.05	79.3	0.99	1.42	58.9	1.07	1.77	44.9	1.13	2.19	35.5	1.20	2.62	26.9	1.29	3.22	22.9	1.35	3.60	18.7	1.45	4.12
80	170.4	0.88	0.79	121.6	0.93	1.05	84.4	0.99	1.42	62.7	1.07	1.77	47.8	1.13	2.20	37.8	1.20	2.63	28.6	1.28	3.24	24.4	1.35	3.60	20.0	1.46	4.08
90	191.1	0.88	0.80	136.5	0.93	1.05	94.8	0.99	1.42	70.4	1.07	1.78	53.7	1.13	2.20	42.4	1.19	2.65	32.1	1.28	3.26	27.4	1.35	3.62	22.4	1.45	4.13
100	211.8	0.88	0.80	151.2	0.93	1.05	105.1	0.99	1.42	78.1	1.07	1.78	59.6	1.13	2.20	47.1	1.20	2.64	35.7	1.29	3.24	30.4	1.35	3.63	24.9	1.45	4.12
110	232.3	0.88	0.80	165.9	0.93	1.06	115.3	0.99	1.43	85.8	1.07	1.78	65.4	1.13	2.21	51.7	1.19	2.65	39.2	1.29	3.25	[illegible]	1.35	3.63	27.3	1.44	4.16
120	252.7	0.88	0.80	180.5	0.93	1.06	125.5	0.99	1.43	93.4	1.07	1.78	71.2	1.13	2.22	56.3	1.19	2.66	42.7	1.28	3.26	36.3	1.34	3.66	29.8	1.45	4.14
130	273.0	0.88	0.80	195.1	0.93	1.06	135.6	0.99	1.43	101.0	1.07	1.79	77.0	1.13	2.22	60.9	1.19	2.66	46.2	1.29	3.26	39.3	1.34	3.66	32.2	1.44	4.16
140	293.2	0.88	0.80	209.5	0.93	1.06	145.7	0.99	1.44	108.5	1.07	1.79	82.8	1.13	2.22	65.5	1.20	2.66	49.6	1.28	3.28	42.3	1.35	3.66	34.6	1.44	4.18
150	313.3	0.88	0.81	223.9	0.93	1.07	155.8	0.99	1.44	116.0	1.07	1.80	88.6	1.13	2.22	70.1	1.20	2.66	53.1	1.28	3.28	45.3	1.35	3.66	37.1	1.45	4.17
160	333.2	0.88	0.81	238.2	0.93	1.07	165.8	1.00	1.44	123.5	1.07	1.80	94.3	1.13	2.23	74.6	1.20	2.67	56.6	1.28	3.28	48.2	1.35	3.67	39.5	1.44	4.18
170	353.1	0.88	0.81	252.4	0.93	1.07	175.8	1.00	1.44	131.0	1.07	1.80	100.0	1.13	2.23	79.2	1.20	2.67	60.0	1.28	3.29	51.2	1.35	3.67	41.9	1.44	4.19
180	372.8	0.88	0.81	266.5	0.93	1.07	185.7	1.00	1.45	138.4	1.07	1.80	105.7	1.13	2.24	83.7	1.20	2.68	63.5	1.28	3.29	54.1	1.35	3.68	44.3	1.44	4.20
190	392.4	0.88	0.81	280.6	0.93	1.08	195.6	1.00	1.45	145.8	1.07	1.81	111.4	1.13	2.24	88.2	1.20	2.68	66.9	1.28	3.30	57.0	1.34	3.69	46.7	1.44	4.21
200	411.9	0.88	0.82	294.6	0.93	1.08	205.4	1.00	1.45	153.2	1.07	1.81	117.1	1.14	2.24	92.7	1.20	2.68	70.3	1.28	3.30	60.0	1.35	3.68	49.1	1.44	4.21
220	451.9	0.88	0.82	323.2	0.93	1.08	225.4	1.00	1.46	168.2	1.07	1.81	128.6	1.14	2.24	101.9	1.20	2.68	77.2	1.28	3.31	65.9	1.35	3.69	54.0	1.44	4.21
240	491.6	0.88	0.82	351.6	0.93	1.09	245.3	1.00	1.46	183.2	1.07	1.81	140.0	1.14	2.25	110.9	1.20	2.69	84.1	1.28	3.32	71.8	1.35	3.70	58.8	1.44	4.22
260	531.0	0.88	0.82	379.9	0.93	1.09	265.2	1.00	1.46	198.0	1.07	1.82	151.5	1.14	2.25	120.0	1.20	2.69	91.0	1.28	3.32	77.7	1.35	3.70	63.7	1.44	4.21
280	570.3	0.88	0.82	408.0	0.93	1.09	284.9	1.00	1.47	212.9	1.08	1.82	162.8	1.14	2.25	129.0	1.20	2.70	97.9	1.28	3.32	83.5	1.35	3.71	68.5	1.44	4.22
300	609.3	0.88	0.83	436.0	0.93	1.09	304.6	1.00	1.47	227.6	1.08	1.83	174.2	1.14	2.25	138.1	1.20	2.69	104.8	1.29	3.32	89.4	1.35	3.71	73.3	1.44	4.23

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

Sheet 10 of 14)

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 5.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	34.8	0.80	0.79	25.2	0.86	1.02	17.7	0.92	1.36	14.3	0.96	1.61	10.6	1.04	2.00	8.4	1.12	2.34	6.7	1.23	2.67	5.4	1.36	3.00			
20	46.3	0.80	0.79	33.5	0.86	1.02	23.5	0.92	1.37	19.0	0.96	1.62	14.1	1.04	2.02	11.1	1.10	2.41	8.8	1.19	2.81	7.0	1.28	3.29	6.1	1.40	3.44
25	57.7	0.80	0.80	41.7	0.86	1.03	29.3	0.92	1.38	23.7	0.96	1.63	17.5	1.03	2.06	13.8	1.09	2.46	10.9	1.17	2.90	8.7	1.26	3.37	7.5	1.35	3.64
30	69.0	0.80	0.80	49.9	0.86	1.04	35.0	0.91	1.39	28.3	0.95	1.65	21.0	1.03	2.06	16.6	1.10	2.44	13.0	1.15	2.96	10.4	1.25	3.41	8.9	1.32	3.78
35	80.3	0.80	0.80	58.1	0.86	1.04	40.8	0.91	1.39	33.0	0.95	1.65	24.4	1.02	2.08	19.3	1.09	2.46	15.2	1.16	2.94	12.1	1.24	3.45	10.3	1.30	3.87
40	91.5	0.81	0.80	66.2	0.86	1.04	46.5	0.91	1.40	37.6	0.95	1.66	27.8	1.02	2.09	22.0	1.09	2.47	17.3	1.15	2.97	13.8	1.24	3.47	11.8	1.30	3.85
45	102.6	0.81	0.81	74.2	0.86	1.05	52.2	0.91	1.40	42.2	0.95	1.66	31.3	1.03	2.08	24.7	1.09	2.48	19.4	1.15	2.99	15.4	1.22	3.55	13.2	1.29	3.91
50	113.7	0.81	0.81	82.3	0.86	1.05	57.9	0.92	1.40	46.8	0.95	1.66	34.7	1.03	2.08	27.3	1.08	2.51	21.5	1.15	3.01	17.1	1.22	3.55	14.7	1.30	3.88
55	124.7	0.81	0.81	90.2	0.86	1.05	63.5	0.91	1.41	51.4	0.96	1.66	38.0	1.02	2.11	30.0	1.08	2.51	23.7	1.15	2.98	18.8	1.22	3.55	16.1	1.29	3.93
60	135.7	0.81	0.81	98.2	0.86	1.05	69.1	0.91	1.41	56.0	0.96	1.66	41.4	1.02	2.11	32.7	1.08	2.51	25.8	1.15	3.00	20.5	1.22	3.55	17.5	1.28	3.97
65	146.5	0.81	0.81	106.1	0.86	1.05	74.7	0.92	1.41	60.5	0.96	1.67	44.8	1.02	2.10	35.3	1.08	2.53	27.9	1.15	3.00	22.1	1.22	3.59	18.9	1.28	4.00
70	157.3	0.81	0.82	113.9	0.86	1.06	80.2	0.91	1.42	65.0	0.96	1.67	48.1	1.02	2.11	38.0	1.08	2.53	30.0	1.15	3.01	23.8	1.22	3.58	20.4	1.29	3.96
75	168.1	0.81	0.82	121.7	0.86	1.06	85.8	0.92	1.42	69.5	0.96	1.67	51.4	1.02	2.12	40.6	1.08	2.54	32.0	1.15	3.04	25.4	1.21	3.62	21.8	1.28	3.98
80	178.8	0.81	0.82	129.4	0.86	1.06	91.3	0.92	1.42	74.0	0.96	1.67	54.8	1.02	2.12	43.3	1.09	2.53	34.1	1.15	3.04	27.1	1.22	3.61	23.2	1.28	4.00
90	200.5	0.81	0.82	145.2	0.86	1.07	102.4	0.92	1.43	83.0	0.96	1.68	61.5	1.02	2.12	48.6	1.08	2.54	38.3	1.15	3.05	30.4	1.21	3.63	26.1	1.28	4.00
100	222.2	0.81	0.82	160.9	0.86	1.07	113.5	0.92	1.43	92.1	0.96	1.68	68.2	1.02	2.13	53.9	1.08	2.54	42.5	1.15	3.05	33.8	1.22	3.61	28.9	1.28	4.03
110	243.7	0.81	0.82	176.5	0.86	1.07	124.6	0.92	1.43	101.0	0.96	1.69	74.8	1.02	2.14	59.2	1.09	2.55	46.7	1.15	3.05	37.1	1.22	3.63	31.8	1.28	4.02
120	265.0	0.81	0.83	192.0	0.86	1.07	135.6	0.92	1.43	110.0	0.96	1.69	81.4	1.02	2.15	64.4	1.08	2.56	50.8	1.15	3.07	40.4	1.21	3.64	34.6	1.28	4.04
130	286.3	0.81	0.83	207.5	0.86	1.08	146.6	0.92	1.43	118.9	0.96	1.69	88.1	1.02	2.14	69.7	1.09	2.56	55.0	1.15	3.06	43.7	1.21	3.65	37.5	1.28	4.03
140	307.4	0.81	0.83	222.8	0.86	1.08	157.5	0.92	1.44	127.8	0.96	1.69	94.6	1.02	2.15	74.9	1.08	2.57	59.1	1.15	3.07	47.0	1.21	3.65	40.3	1.28	4.04
150	328.4	0.81	0.83	238.1	0.87	1.08	168.3	0.92	1.44	136.6	0.96	1.70	101.2	1.02	2.15	80.1	1.08	2.57	63.2	1.15	3.08	50.2	1.21	3.67	43.1	1.28	4.05
160	349.3	0.81	0.83	253.2	0.86	1.08	179.1	0.92	1.44	145.4	0.96	1.70	107.7	1.02	2.16	85.3	1.09	2.57	67.3	1.15	3.09	53.5	1.21	3.67	45.9	1.28	4.06
170	370.0	0.81	0.84	268.3	0.87	1.09	189.9	0.92	1.45	154.1	0.96	1.70	114.2	1.02	2.16	90.4	1.08	2.58	71.4	1.15	3.09	56.8	1.21	3.67	48.7	1.28	4.07
180	390.7	0.82	0.84	283.3	0.87	1.09	200.6	0.92	1.45	162.9	0.96	1.70	120.7	1.02	2.17	95.6	1.09	2.58	75.5	1.15	3.09	60.0	1.21	3.69	51.5	1.28	4.07
190	411.2	0.82	0.84	298.2	0.87	1.09	211.2	0.92	1.45	171.5	0.96	1.71	127.1	1.02	2.17	100.7	1.08	2.59	79.6	1.15	3.09	63.3	1.21	3.68	54.3	1.28	4.07
200	431.6	0.82	0.84	313.0	0.87	1.09	221.8	0.92	1.46	180.2	0.96	1.71	133.5	1.02	2.18	105.8	1.09	2.59	83.6	1.15	3.10	66.5	1.21	3.69	57.1	1.28	4.08
220	473.3	0.82	0.84	343.4	0.87	1.10	243.4	0.92	1.46	197.8	0.97	1.71	146.6	1.02	2.18	116.2	1.09	2.60	91.9	1.15	3.10	73.1	1.22	3.69	62.7	1.28	4.09
240	514.8	0.82	0.84	373.6	0.87	1.10	264.9	0.92	1.46	215.3	0.97	1.72	159.6	1.02	2.18	126.5	1.09	2.60	100.1	1.15	3.10	79.6	1.21	3.70	68.3	1.28	4.09
260	556.1	0.82	0.85	403.6	0.87	1.10	286.3	0.92	1.46	232.7	0.97	1.72	172.6	1.03	2.19	136.8	1.09	2.61	108.2	1.15	3.11	86.1	1.21	3.71	73.9	1.28	4.10
280	597.1	0.82	0.85	433.5	0.87	1.10	307.6	0.92	1.47	250.1	0.97	1.72	185.5	1.03	2.19	147.1	1.09	2.61	116.4	1.15	3.11	92.6	1.21	3.71	79.5	1.28	4.10
300	638.0	0.82	0.85	463.1	0.87	1.11	328.7	0.92	1.47	267.4	0.97	1.73	198.4	1.03	2.19	157.3	1.09	2.61	124.5	1.15	3.12	99.1	1.22	3.71	85.1	1.28	4.10

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 11 of 14)

4-38467 8-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 6.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	40.5	0.72	0.76	26.9	0.81	1.02	19.6	0.85	1.34	14.8	0.90	1.66	11.7	0.96	1.97	9.4	1.02	2.31	7.6	1.09	2.67	6.1	1.18	3.05	5.0	1.32	3.33
20	53.9	0.72	0.76	35.7	0.81	1.03	26.1	0.85	1.34	19.6	0.89	1.69	15.6	0.96	1.97	12.5	1.01	2.33	10.1	1.08	2.71	8.0	1.14	3.23	6.5	1.24	3.63
25	67.1	0.72	0.76	44.5	0.81	1.03	32.5	0.85	1.35	24.5	0.90	1.69	19.4	0.95	2.00	15.5	1.00	2.39	12.5	1.06	2.80	10.0	1.14	3.24	8.1	1.23	3.69
30	80.3	0.72	0.76	53.2	0.80	1.04	38.9	0.85	1.35	29.3	0.89	1.70	23.3	0.96	1.99	18.6	1.00	2.39	15.0	1.06	2.80	11.9	1.12	3.32	9.6	1.20	3.84
35	93.4	0.72	0.76	61.9	0.81	1.04	45.3	0.85	1.35	34.1	0.89	1.70	27.1	0.96	2.00	21.6	0.99	2.42	17.4	1.05	2.84	13.9	1.13	3.31	11.2	1.20	3.84
40	106.4	0.73	0.77	70.6	0.81	1.04	51.6	0.85	1.36	38.9	0.89	1.71	30.9	0.95	2.01	24.7	1.00	2.41	19.9	1.05	2.83	15.8	1.12	3.36	12.7	1.19	3.93
45	119.3	0.73	0.77	79.2	0.81	1.04	57.9	0.85	1.36	43.7	0.90	1.71	34.6	0.95	2.03	27.7	1.00	2.42	22.3	1.05	2.86	17.7	1.11	3.40	14.3	1.19	3.92
50	132.1	0.73	0.77	87.7	0.81	1.05	64.1	0.84	1.37	48.4	0.89	1.71	38.4	0.95	2.03	30.7	0.99	2.43	24.7	1.05	2.87	19.7	1.12	3.38	15.8	1.18	3.98
55	144.9	0.73	0.77	96.2	0.81	1.05	70.4	0.85	1.37	53.1	0.89	1.72	42.2	0.95	2.03	33.7	0.99	2.44	27.1	1.04	2.89	21.6	1.11	3.40	17.4	1.18	3.96
60	157.5	0.73	0.77	104.6	0.81	1.05	76.5	0.84	1.38	57.8	0.89	1.72	45.9	0.95	2.04	36.7	1.00	2.44	29.6	1.05	2.87	23.5	1.11	3.42	18.9	1.18	4.01
65	170.1	0.73	0.78	113.0	0.81	1.06	82.7	0.85	1.38	62.5	0.90	1.72	49.6	0.95	2.04	39.7	1.00	2.44	32.0	1.05	2.88	25.4	1.11	3.43	20.5	1.18	3.98
70	182.6	0.73	0.78	121.3	0.81	1.06	88.8	0.85	1.38	67.2	0.90	1.72	53.3	0.95	2.05	42.7	1.00	2.44	34.4	1.05	2.88	27.4	1.11	3.41	22.0	1.18	4.01
75	195.1	0.73	0.78	129.6	0.81	1.06	94.9	0.85	1.39	71.8	0.90	1.73	57.0	0.95	2.05	45.6	1.00	2.46	36.7	1.04	2.91	29.3	1.11	3.42	23.6	1.18	3.99
80	207.4	0.73	0.78	137.8	0.81	1.06	100.9	0.85	1.39	76.4	0.90	1.73	60.6	0.95	2.06	48.6	1.00	2.45	39.1	1.05	2.91	31.2	1.11	3.42	25.1	1.18	4.02
90	232.6	0.73	0.78	154.5	1.81	1.07	113.2	0.85	1.40	85.8	0.90	1.73	68.1	0.95	2.06	54.6	1.00	2.45	43.9	1.05	2.92	35.0	1.11	3.44	28.2	1.18	4.02
100	257.7	0.73	0.78	171.2	0.81	1.07	125.5	0.85	1.40	95.1	0.90	1.74	75.5	0.95	2.06	60.5	1.00	2.46	48.7	1.05	2.92	38.8	1.11	3.46	31.3	1.18	4.03
110	282.6	0.74	0.78	187.8	0.81	1.07	137.7	0.85	1.40	104.4	0.90	1.74	82.8	0.95	2.07	66.4	1.00	2.47	53.5	1.05	2.92	42.6	1.11	3.47	34.4	1.18	4.03
120	307.3	0.74	0.79	204.2	0.81	1.08	149.8	0.85	1.40	113.6	0.90	1.74	90.2	0.95	2.07	72.3	1.00	2.47	58.3	1.05	2.92	46.4	1.11	3.47	37.4	1.18	4.06
130	331.9	0.74	0.79	220.6	0.81	1.08	161.9	0.85	1.41	122.8	0.90	1.75	97.5	0.95	2.08	78.2	1.00	2.48	63.0	1.05	2.93	50.2	1.11	3.48	40.5	1.18	4.05
140	356.3	0.74	0.79	236.8	0.81	1.08	173.9	0.85	1.41	131.9	0.90	1.75	104.7	0.95	2.09	84.0	1.00	2.48	67.7	1.05	2.94	54.0	1.11	3.48	43.5	1.18	4.07
150	380.5	0.74	0.79	253.0	0.81	1.09	185.8	0.85	1.41	141.0	0.90	1.75	112.0	0.96	2.09	89.9	1.00	2.48	72.5	1.05	2.93	57.8	1.11	3.48	46.6	1.18	4.06
160	404.6	0.74	0.79	269.0	0.81	1.09	197.7	0.85	1.42	150.1	0.90	1.76	119.2	0.96	2.09	95.7	1.00	2.49	77.2	1.05	2.94	61.5	1.11	3.49	49.6	1.18	4.08
170	428.6	0.74	0.79	285.0	0.81	1.09	209.5	0.85	1.42	159.1	0.90	1.76	126.4	0.96	2.09	101.5	1.00	2.49	81.8	1.05	2.95	65.3	1.11	3.49	52.7	1.18	4.07
180	452.4	0.74	0.79	300.8	0.81	1.09	221.3	0.85	1.42	168.1	0.90	1.76	133.5	0.96	2.10	107.2	1.00	2.50	86.5	1.05	2.95	69.0	1.11	3.49	55.7	1.18	4.08
190	476.1	0.74	0.80	316.6	0.81	1.10	233.0	0.85	1.42	177.0	0.90	1.77	140.6	0.96	2.10	113.0	1.00	2.50	91.1	1.05	2.96	72.7	1.11	3.50	58.7	1.18	4.08
200	499.6	0.74	0.80	332.3	0.81	1.10	244.6	0.85	1.43	185.9	0.90	1.77	147.7	0.96	2.11	118.7	1.00	2.50	95.8	1.05	2.96	76.4	1.11	3.51	61.7	1.18	4.09
220	547.7	0.74	0.80	364.5	0.81	1.10	268.4	0.85	1.43	204.1	0.91	1.77	162.1	0.96	2.11	130.3	1.00	2.51	105.2	1.05	2.96	83.9	1.11	3.51	67.8	1.18	4.09
240	595.6	0.74	0.80	396.5	0.81	1.11	292.1	0.85	1.43	222.1	0.91	1.78	176.5	0.96	2.11	141.9	1.00	2.51	114.5	1.05	2.97	91.4	1.11	3.52	73.8	1.18	4.11
260	643.2	0.74	0.80	428.3	0.81	1.11	315.7	0.85	1.43	240.1	0.91	1.78	190.7	0.96	2.12	153.4	1.00	2.52	123.9	1.05	2.97	98.9	1.11	3.52	79.9	1.18	4.10
280	690.5	0.75	0.81	459.9	0.81	1.11	339.1	0.85	1.44	258.0	0.91	1.78	205.0	0.96	2.12	164.9	1.00	2.52	133.2	1.05	2.97	106.3	1.11	3.53	85.9	1.18	4.11
300	737.5	0.75	0.81	491.4	0.81	1.11	362.4	0.85	1.44	275.8	0.91	1.78	219.1	0.96	2.13	176.3	1.00	2.52	142.4	1.05	2.98	113.7	1.11	3.53	91.9	1.18	4.12

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 12 of 14)

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 8.0 Percent

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	43.1	0.64	0.80	31.6	0.71	0.98	22.2	0.76	1.31	18.0	0.79	1.56	13.7	0.84	1.92	11.0	0.89	2.26	9.2	0.95	2.54	7.4	0.99	3.00	6.2	1.09	3.26
20	57.3	0.64	0.80	42.0	0.71	0.99	29.5	0.76	1.32	24.0	0.79	1.56	18.2	0.84	1.94	14.7	0.89	2.25	12.2	0.93	2.59	9.8	0.98	3.08	8.1	1.04	3.49
25	71.4	0.65	0.80	52.3	0.71	0.99	36.7	0.76	1.33	29.9	0.79	1.57	22.7	0.84	1.95	18.3	0.89	2.28	15.2	0.93	2.62	12.2	0.97	3.12	10.1	1.04	3.53
30	85.4	0.65	0.80	62.6	0.71	0.99	43.9	0.76	1.33	35.8	0.79	1.57	27.2	0.84	1.95	21.9	0.89	2.29	18.1	0.92	2.67	14.6	0.97	3.15	12.1	1.03	3.55
35	99.3	0.65	0.80	72.8	0.72	0.99	51.1	0.76	1.34	41.6	0.79	1.58	31.7	0.84	1.95	25.5	0.89	2.30	21.1	0.92	2.67	17.0	0.96	3.16	14.0	1.02	3.64
40	113.1	0.65	0.81	82.9	0.72	1.00	58.2	0.76	1.34	47.4	0.79	1.59	36.1	0.84	1.96	29.0	0.88	2.32	24.1	0.92	2.67	19.4	0.96	3.17	16.0	1.02	3.63
45	126.8	0.65	0.81	93.0	0.72	1.00	65.3	0.76	1.34	53.2	0.79	1.59	40.5	0.84	1.97	32.6	0.88	2.32	27.0	0.92	2.69	21.8	0.97	3.17	18.0	1.02	3.62
50	140.4	0.65	0.81	102.9	0.72	1.01	72.3	0.76	1.35	59.0	0.79	1.59	44.9	0.84	1.97	36.1	0.88	2.33	30.0	0.92	2.68	24.2	0.97	3.17	19.9	1.02	3.67
55	153.9	0.65	0.81	112.8	0.72	1.01	79.3	0.76	1.35	64.7	0.79	1.60	49.3	0.84	1.97	39.6	0.88	2.34	32.9	0.92	2.70	26.5	0.96	3.20	21.9	1.02	3.65
60	167.3	0.65	0.81	122.7	0.72	1.01	86.2	0.76	1.36	70.4	0.79	1.60	53.7	0.84	1.97	43.1	0.88	2.34	35.8	0.92	2.70	28.9	0.97	3.19	23.8	1.02	3.69
65	180.6	0.65	0.82	132.4	0.72	1.01	93.1	0.76	1.36	76.0	0.79	1.61	58.0	0.84	1.98	46.6	0.88	2.35	38.7	0.92	2.71	31.3	0.97	3.18	25.7	1.01	3.71
70	193.9	0.65	0.82	142.2	0.72	1.01	100.0	0.76	1.37	81.7	0.79	1.61	62.3	0.84	1.98	50.1	0.88	2.35	41.6	0.92	2.71	33.6	0.97	3.20	27.7	1.02	3.69
75	207.0	0.65	0.82	151.8	0.72	1.02	106.8	0.76	1.37	87.2	0.79	1.62	66.6	0.84	1.99	53.5	0.88	2.36	44.5	0.92	2.72	35.9	0.96	3.22	29.6	1.02	3.71
80	220.1	0.66	0.82	161.4	0.72	1.02	113.6	0.76	1.37	92.8	0.79	1.62	70.9	0.84	1.99	56.9	0.88	2.37	47.3	0.92	2.73	38.2	0.96	3.23	31.5	1.01	3.72
90	246.8	0.66	0.82	180.9	0.72	1.02	127.4	0.76	1.38	104.1	0.79	1.62	79.5	0.84	2.00	63.9	0.88	2.37	53.1	0.92	2.74	42.9	0.96	3.23	35.4	1.02	3.72
100	273.3	0.66	0.82	200.3	0.72	1.03	141.1	0.76	1.38	115.4	0.79	1.62	88.1	0.84	2.00	70.8	0.88	2.38	58.9	0.92	2.74	47.6	0.97	3.24	39.2	1.01	3.75
110	299.6	0.66	0.83	219.6	0.72	1.03	154.8	0.76	1.38	126.5	0.79	1.63	96.7	0.84	2.01	77.7	0.88	2.38	64.7	0.92	2.74	52.3	0.97	3.23	43.1	1.02	3.74
120	325.7	0.66	0.83	238.8	0.72	1.03	168.4	0.76	1.39	137.7	0.79	1.63	105.3	0.84	2.01	84.6	0.88	2.39	70.4	0.92	2.75	56.9	0.97	3.25	46.9	1.01	3.75
130	351.7	0.66	0.83	257.9	0.72	1.04	181.9	0.76	1.39	148.7	0.79	1.64	113.8	0.84	2.01	91.4	0.88	2.40	76.1	0.92	2.75	61.6	0.97	3.24	50.7	1.01	3.76
140	377.5	0.66	0.83	276.8	0.72	1.04	195.3	0.76	1.39	159.7	0.79	1.64	122.2	0.84	2.02	98.2	0.88	2.40	81.8	0.92	2.76	66.2	0.97	3.25	54.5	1.01	3.77
150	403.1	0.66	0.83	295.6	0.72	1.04	208.6	0.76	1.40	170.7	0.80	1.64	130.6	0.84	2.02	105.0	0.88	2.40	87.4	0.92	2.77	70.8	0.97	3.25	58.3	1.01	3.78
160	428.5	0.66	0.83	314.2	0.72	1.04	221.9	0.76	1.40	181.5	0.79	1.65	139.0	0.85	2.02	111.7	0.88	2.41	93.1	0.92	2.77	75.3	0.97	3.27	62.1	1.01	3.78
170	453.8	0.66	0.84	332.8	0.72	1.05	235.1	0.76	1.40	192.4	0.80	1.65	147.3	0.85	2.03	118.4	0.88	2.42	98.7	0.92	2.77	79.9	0.97	3.27	65.9	1.02	3.78
180	478.9	0.66	0.84	351.2	0.72	1.05	248.2	0.76	1.41	203.1	0.80	1.65	155.6	0.85	2.03	125.1	0.88	2.42	104.3	0.93	2.78	84.4	0.97	3.28	69.6	1.02	3.79
190	503.9	0.66	0.84	369.5	0.72	1.05	261.2	0.77	1.41	213.8	0.80	1.66	163.9	0.85	2.03	131.8	0.89	2.42	109.8	0.92	2.79	89.0	0.97	3.27	73.4	1.02	3.79
200	528.5	0.67	0.84	387.7	0.73	1.05	274.1	0.77	1.42	224.4	0.80	1.66	172.1	0.85	2.04	138.4	0.89	2.43	115.3	0.92	2.79	93.5	0.97	3.28	77.1	1.02	3.80
220	579.5	0.67	0.84	425.1	0.73	1.06	300.7	0.77	1.42	246.2	0.80	1.66	188.8	0.85	2.04	151.8	0.88	2.44	126.6	0.93	2.80	102.6	0.97	3.29	84.7	1.02	3.80
240	630.1	0.67	0.84	462.2	0.73	1.06	327.0	0.77	1.42	267.9	0.80	1.67	205.5	0.85	2.05	165.2	0.89	2.44	137.8	0.93	2.80	111.8	0.97	3.29	92.2	1.02	3.81
260	680.4	0.67	0.85	499.1	0.73	1.06	353.3	0.77	1.42	289.4	0.80	1.67	222.1	0.85	2.05	178.6	0.89	2.45	149.0	0.93	2.80	120.8	0.97	3.30	99.7	1.02	3.82
280	730.4	0.67	0.85	535.6	0.73	1.07	379.3	0.77	1.43	310.8	0.80	1.68	238.6	0.85	2.05	191.9	0.89	2.45	160.1	0.93	2.81	129.9	0.97	3.30	107.2	1.02	3.82
300	780.0	0.67	0.85	572.1	0.73	1.07	405.2	0.77	1.43	332.1	0.80	1.68	255.0	0.85	2.06	205.1	0.89	2.46	171.2	0.93	2.81	138.9	0.97	3.31	114.7	1.02	3.82

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 13 of 14)

4-35487 8-68

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "B"**.

Grade 10.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	51.4	0.56	0.77	38.3	0.63	0.92	27.2	0.69	1.18	19.6	0.73	1.56	15.7	0.76	1.86	12.6	0.81	2.18	10.6	0.85	2.45	8.7	0.90	2.83	7.2	0.94	3.26
20	68.2	0.55	0.78	50.9	0.63	0.92	36.2	0.69	1.18	26.1	0.73	1.56	20.9	0.76	1.87	16.8	0.81	2.18	14.0	0.84	2.53	11.5	0.88	2.91	9.5	0.92	3.39
25	85.0	0.56	0.78	63.4	0.63	0.92	45.1	0.69	1.19	32.5	0.73	1.57	26.1	0.76	1.87	20.9	0.80	2.20	17.5	0.84	2.52	14.3	0.87	2.96	11.9	0.92	3.37
30	101.6	0.56	0.78	75.8	0.63	0.92	53.9	0.69	1.20	38.8	0.72	1.58	31.2	0.76	1.88	25.0	0.80	2.22	20.9	0.83	2.55	17.1	0.87	2.98	14.2	0.91	3.42
35	118.1	0.56	0.78	88.1	0.63	0.93	62.7	0.69	1.20	45.2	0.73	1.58	36.3	0.76	1.88	29.1	0.80	2.22	24.3	0.83	2.57	19.9	0.87	3.00	16.5	0.91	3.46
40	134.4	0.56	0.79	100.3	0.64	0.93	71.3	0.69	1.21	51.5	0.73	1.59	41.3	0.76	1.90	33.2	0.80	2.22	27.7	0.83	2.58	22.7	0.87	3.00	18.9	0.91	3.43
45	150.7	0.56	0.79	112.5	0.64	0.93	80.0	0.69	1.21	57.7	0.72	1.60	46.4	0.76	1.90	37.2	0.80	2.24	31.1	0.83	2.58	25.5	0.87	3.01	21.2	0.91	3.45
50	166.8	0.56	0.79	124.5	0.64	0.93	88.5	0.69	1.21	63.9	0.72	1.60	51.3	0.76	1.91	41.3	0.80	2.23	34.5	0.83	2.58	28.3	0.87	3.01	23.5	0.91	3.46
55	182.8	0.56	0.79	136.4	0.64	0.93	97.1	0.69	1.21	70.1	0.73	1.60	56.3	0.76	1.92	45.3	0.80	2.24	37.8	0.83	2.60	31.1	0.87	3.00	25.8	0.91	3.47
60	198.6	0.56	0.79	148.2	0.64	0.94	105.5	0.69	1.22	76.2	0.72	1.61	61.2	0.76	1.92	49.3	0.80	2.25	41.1	0.83	2.61	33.8	0.87	3.02	28.1	0.91	3.47
65	214.3	0.57	0.79	160.0	0.64	0.94	113.9	0.69	1.22	32.3	0.73	1.62	66.2	0.76	1.92	53.2	0.80	2.26	44.4	0.83	2.62	36.5	0.87	3.04	30.3	0.91	3.51
70	229.9	0.57	0.79	171.6	0.64	0.94	122.2	0.69	1.23	88.4	0.73	1.62	71.0	0.76	1.93	57.2	0.80	2.26	47.7	0.83	2.63	39.3	0.87	3.03	32.6	0.91	3.50
75	245.4	0.57	0.80	183.2	0.64	0.94	130.5	0.69	1.23	94.4	0.73	1.62	75.9	0.76	1.94	61.1	0.80	2.27	51.0	0.83	2.63	42.0	0.87	3.04	34.9	0.91	3.50
80	260.7	0.57	0.80	194.6	0.64	0.95	138.6	0.69	1.24	100.3	0.73	1.63	80.7	0.76	1.94	65.0	0.80	2.27	54.3	0.83	2.63	44.7	0.87	3.04	37.1	0.91	3.52
90	292.1	0.57	0.80	218.1	0.64	0.95	155.4	0.69	1.24	112.5	0.73	1.64	90.5	0.76	1.95	73.0	0.81	2.27	60.9	0.83	2.64	50.1	0.87	3.06	41.7	0.91	3.52
100	323.3	0.57	0.80	241.5	0.64	0.95	172.1	0.69	1.24	124.6	0.73	1.64	100.3	0.76	1.95	80.9	0.81	2.28	67.5	0.83	2.65	55.6	0.87	3.06	46.2	0.91	3.53
110	354.3	0.57	0.80	264.6	0.64	0.96	188.6	0.69	1.25	136.7	0.73	1.64	110.0	0.76	1.96	88.7	0.81	2.29	74.1	0.83	2.65	61.0	0.87	3.07	50.7	0.91	3.54
120	385.0	0.57	0.80	287.6	0.64	0.96	205.0	0.69	1.25	148.7	0.73	1.65	119.6	0.76	1.97	96.5	0.81	2.29	80.6	0.83	2.66	66.4	0.87	3.08	55.2	0.91	3.55
130	415.5	0.57	0.81	310.3	0.65	0.96	221.3	0.69	1.26	160.6	0.73	1.65	129.3	0.76	1.97	104.3	0.81	2.30	87.1	0.83	2.67	71.8	0.87	3.08	59.7	0.91	3.55
140	445.7	0.57	0.81	333.0	0.65	0.96	237.5	0.69	1.26	172.5	0.73	1.65	138.8	0.76	1.97	112.1	0.81	2.30	93.5	0.83	2.68	77.1	0.87	3.09	64.2	0.91	3.55
150	475.7	0.58	0.81	355.4	0.65	0.97	253.6	0.69	1.26	184.2	0.73	1.66	148.4	0.76	1.97	119.8	0.81	2.30	100.0	0.83	2.68	82.5	0.88	3.09	68.6	0.91	3.57
160	505.5	0.58	0.81	377.7	0.65	0.97	269.5	0.69	1.27	195.9	0.73	1.66	157.8	0.76	1.98	127.4	0.81	2.31	106.4	0.83	2.69	87.8	0.88	3.10	73.0	0.91	3.58
170	535.0	0.58	0.81	399.7	0.65	0.97	285.3	0.69	1.27	207.6	0.73	1.66	167.2	0.76	1.98	135.0	0.81	2.32	112.8	0.83	2.69	93.0	0.87	3.11	77.5	0.91	3.57
180	564.3	0.58	0.81	421.7	0.65	0.97	301.0	0.70	1.28	219.1	0.73	1.67	176.6	0.76	1.99	142.6	0.81	2.32	119.1	0.83	2.70	98.3	0.88	3.11	81.8	0.91	3.59
190	593.4	0.58	0.82	443.4	0.65	0.98	316.6	0.70	1.28	230.6	0.73	1.67	185.9	0.76	1.99	150.1	0.81	2.33	125.4	0.83	2.71	103.5	0.88	3.12	86.2	0.91	3.59
200	622.2	0.58	0.82	465.0	0.65	0.98	332.1	0.70	1.28	242.1	0.73	1.68	195.2	0.76	1.99	157.6	0.81	2.33	131.7	0.83	2.71	108.7	0.88	3.13	90.6	0.92	3.59
220	681.9	0.58	0.82	509.6	0.65	0.98	364.1	0.70	1.29	265.5	0.73	1.68	214.1	0.76	2.00	173.0	0.81	2.33	144.6	0.83	2.71	119.3	0.88	3.13	99.4	0.91	3.60
240	741.1	0.58	0.82	553.8	0.65	0.99	395.9	0.70	1.29	288.8	0.73	1.68	233.0	0.76	2.00	188.2	0.81	2.34	157.4	0.84	2.72	129.9	0.88	3.13	108.3	0.92	3.60
260	799.9	0.58	0.82	597.7	0.65	0.99	427.4	0.70	1.29	312.0	0.73	1.69	251.7	0.77	2.01	203.4	0.81	2.34	170.1	0.84	2.72	140.4	0.88	3.14	117.0	0.92	3.61
280	858.2	0.58	0.83	641.3	0.65	0.99	458.7	0.70	1.30	335.0	0.73	1.69	270.4	0.77	2.01	218.5	0.81	2.35	182.7	0.84	2.73	150.9	0.88	3.15	125.8	0.92	3.62
300	916.0	0.59	0.83	684.6	0.65	0.99	489.8	0.70	1.30	357.9	0.73	1.69	289.0	0.77	2.01	233.5	0.81	2.35	195.4	0.84	2.73	161.3	0.88	3.15	134.5	0.92	3.62

Exhibit 7-4 Parabolic waterway design
(Retardance "D" and "B")

(Sheet 14 of 14)

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 0.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	9.6	2.36	1.63																								
30	11.4	2.31	1.68																								
35	13.2	2.27	1.73																								
40	15.0	2.25	1.76	10.4	2.67	2.13																					
45	16.8	2.23	1.78	11.6	2.62	2.19																					
50	18.6	2.21	1.80	12.8	2.59	2.24																					
55	20.4	2.20	1.82	14.0	2.56	2.28																					
60	22.2	2.19	1.83	15.2	2.53	2.31																					
65	24.0	2.18	1.84	16.5	2.54	2.30																					
70	25.8	2.18	1.85	17.7	2.52	2.33	12.6	3.05	2.70																		
75	27.6	2.17	1.86	18.9	2.51	2.35	13.4	3.00	2.76																		
80	29.4	2.17	1.87	20.1	2.50	2.37	14.3	3.01	2.76																		
90	33.1	2.17	1.86	22.6	2.49	2.38	16.0	2.97	2.81																		
100	36.7	2.17	1.87	25.1	2.49	2.38	17.7	2.95	2.85																		
110	40.3	2.16	1.88	27.5	2.47	2.41	19.4	2.93	2.88																		
120	43.9	2.16	1.89	30.0	2.47	2.41	21.1	2.91	2.91	15.2	3.58	3.28															
130	47.6	2.16	1.88	32.5	2.48	2.41	22.8	2.89	2.93	16.4	3.55	3.32															
140	51.2	2.16	1.88	34.9	2.46	2.43	24.6	2.91	2.91	17.6	3.53	3.35															
150	54.8	2.16	1.89	37.4	2.47	2.42	26.3	2.90	2.93	18.8	3.51	3.39															
160	58.4	2.16	1.89	39.9	2.47	2.42	28.0	2.89	2.95	20.0	3.49	3.41															
170	62.0	2.16	1.89	42.3	2.46	2.43	29.7	2.88	2.96	21.2	3.47	3.44	16.7	4.03	3.75												
180	65.6	2.16	1.90	44.8	2.47	2.43	31.4	2.87	2.97	22.4	3.46	3.46	17.6	4.00	3.81												
190	69.2	2.16	1.90	47.2	2.46	2.44	33.1	2.87	2.98	23.6	3.45	3.48	18.5	3.97	3.85												
200	72.8	2.16	1.90	49.7	2.46	2.44	34.9	2.88	2.97	24.8	3.44	3.49	19.4	3.94	3.90												
220	80.0	2.16	1.90	54.6	2.46	2.44	38.3	2.87	2.99	27.2	3.42	3.53	21.3	3.92	3.92												
240	87.3	2.16	1.90	59.5	2.46	2.45	41.7	2.86	3.00	29.6	3.40	3.55	23.1	3.88	3.99												
260	94.5	2.16	1.90	64.5	2.46	2.44	45.2	2.86	3.00	32.1	3.41	3.54	25.0	3.87	4.01	19.5	4.57	4.34									
280	101.7	2.16	1.90	69.4	2.46	2.45	48.6	2.85	3.01	34.5	3.40	3.56	26.9	3.86	4.02	21.0	4.57	4.34									
300	108.9	2.16	1.90	74.3	2.46	2.45	52.1	2.86	3.00	36.9	3.39	3.58	28.7	3.83	4.07	22.4	4.53	4.40									

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 1 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 0.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	8.6	1.63	1.58																								
20	11.3	1.58	1.66																								
25	14.1	1.57	1.67	9.0	1.91	2.14																					
30	16.9	1.56	1.68	10.7	1.87	2.21	8.2	2.18	2.48																		
35	19.6	1.55	1.71	12.4	1.85	2.26	9.4	2.10	2.62																		
40	22.4	1.55	1.71	14.1	1.83	2.30	10.7	2.08	2.66																		
45	25.1	1.54	1.73	15.8	1.82	2.33	11.9	2.03	2.76																		
50	27.9	1.54	1.73	17.5	1.80	2.35	13.2	2.02	2.78	9.6	2.42	3.19															
55	30.7	1.54	1.72	19.2	1.80	2.37	14.5	2.02	2.79	10.5	2.39	3.25															
60	33.4	1.54	1.74	20.9	1.79	2.38	15.8	2.01	2.80	11.4	2.37	3.30															
65	36.1	1.53	1.75	22.7	1.80	2.36	17.0	1.99	2.86	12.3	2.35	3.34															
70	38.9	1.54	1.74	24.4	1.80	2.37	18.3	1.99	2.86	13.2	2.33	3.38															
75	41.6	1.54	1.75	26.1	[illegible]	2.38	19.6	1.99	2.86	14.1	2.32	3.41	11.2	2.71	3.66												
80	44.3	1.53	1.75	27.8	1.79	2.39	20.9	1.99	2.86	15.0	2.31	3.43	11.8	2.65	3.80												
90	49.8	1.53	1.75	31.2	1.78	2.41	23.5	1.99	2.87	16.9	2.31	3.42	13.3	2.65	3.78												
100	55.3	1.53	1.75	34.6	1.78	2.42	26.0	1.97	2.90	18.7	2.29	3.47	14.7	2.63	3.85	11.9	3.02	4.13									
110	60.8	1.54	1.75	38.1	1.78	2.41	28.6	1.97	2.90	20.5	2.28	3.50	16.1	2.60	3.90	13.0	2.98	4.22									
120	66.3	1.54	1.75	41.5	1.78	2.42	31.2	1.98	2.90	22.4	2.29	3.49	17.5	2.58	3.94	14.1	2.94	4.30									
130	71.7	1.53	1.76	44.9	1.78	2.42	33.7	1.97	2.92	24.2	2.28	3.51	18.9	2.57	3.98	15.2	2.91	4.36									
140	77.2	1.54	1.76	48.3	1.78	2.43	36.3	1.97	2.92	26.0	2.27	3.54	20.4	2.58	3.95	16.4	2.93	4.34									
150	82.6	1.54	1.76	51.7	1.78	2.43	38.9	1.97	2.91	27.9	2.28	3.52	21.8	2.57	3.98	17.5	2.90	4.39	14.0	3.34	4.77						
160	88.0	1.53	1.76	55.1	1.78	2.44	41.4	1.97	2.93	29.7	2.27	3.54	23.2	2.56	4.01	18.6	2.88	4.44	14.9	3.33	4.80						
170	93.4	1.53	1.77	58.5	1.78	2.44	44.0	1.97	2.92	31.5	2.26	3.55	24.6	2.55	4.03	19.8	2.89	4.41	15.7	3.27	4.92						
180	98.8	1.53	1.77	61.9	1.78	2.44	46.5	1.96	2.94	33.3	2.26	3.57	26.1	2.56	4.01	20.9	2.88	4.45	16.6	3.26	4.94						
190	104.2	1.54	1.77	65.3	1.78	2.44	49.1	1.97	2.93	35.2	2.27	3.55	27.5	2.56	4.03	22.0	2.86	4.49	17.5	3.26	4.96						
200	109.6	1.54	1.77	68.7	1.78	2.44	51.6	1.96	2.94	37.0	2.26	3.56	28.9	2.55	4.04	23.1	2.85	4.52	18.4	3.25	4.98	15.3	3.72	5.23			
220	120.5	1.54	1.77	75.5	1.78	2.44	56.8	1.97	2.93	40.7	2.26	3.56	31.8	2.55	4.04	25.4	2.85	4.53	20.2	3.24	5.01	16.7	3.66	5.36			
240	131.3	1.54	1.77	82.3	1.78	2.45	61.9	1.97	2.94	44.3	2.26	3.58	34.6	2.54	4.07	27.7	2.85	4.53	22.0	3.23	5.04	18.2	3.65	5.38			
260	142.1	1.54	1.77	89.1	1.78	2.45	67.0	1.97	2.94	48.0	2.26	3.58	37.5	2.55	4.06	30.0	2.85	4.54	23.8	3.22	5.06	19.7	3.64	5.39			
280	152.9	1.54	1.78	95.9	1.78	2.45	72.1	1.97	2.95	51.6	2.25	3.59	40.3	2.54	4.08	32.2	2.83	4.58	25.6	3.21	5.08	21.1	3.61	5.48	17.5	4.14	5.75
300	163.7	1.54	1.78	102.6	1.78	2.46	77.2	1.97	2.95	55.3	2.26	3.59	43.2	2.54	4.08	34.5	2.83	4.58	27.3	3.18	5.15	22.6	3.60	5.49	18.7	4.12	5.80

Exhibit 7-5 Parabolic waterway design
(Retardance "D and "C")

(Sheet 2 of 14)

4-35487 5-88

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 0.75 Percent

Q cfs	V_1 = 2.0			V_1 = . 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	11.7	1.29	1.47	6.8	1.61	2.02																					
20	15.5	1.27	1.51	8.9	1.54	2.15																					
25	19.3	1.26	1.52	11.0	1.50	2.23	8.2	1.74	2.58																		
30	23.1	1.25	1.54	13.2	1.50	2.24	9.7	1.69	2.70	7.7	1.92	2.99															
35	27.0	1.26	1.53	15.3	1.48	2.29	11.3	1.68	2.72	8.9	1.88	3.08															
40	30.8	1.26	1.53	17.5	1.49	2.28	12.8	1.65	2.80	10.1	1.86	3.16															
45	34.5	1.25	1.55	19.6	1.47	2.31	14.4	1.65	2.80	11.3	1.84	3.21															
50	38.3	1.25	1.55	21.8	1.48	2.30	15.9	1.63	2.85	12.5	1.82	3.26	9.3	2.18	3.65												
55	42.1	1.25	1.55	24.0	1.48	2.29	17.5	1.64	2.85	13.7	1.81	3.30	10.1	2.12	3.80												
60	45.9	1.25	1.55	26.1	1.48	2.31	19.1	1.64	2.84	15.0	1.82	3.26	11.0	2.12	3.82												
65	49.6	1.25	1.56	28.2	1.47	2.33	20.6	1.63	2.88	16.2	1.81	3.29	11.9	2.11	3.84	9.9	2.38	4.08									
70	53.4	1.25	1.56	30.4	1.48	2.32	22.2	1.63	2.87	17.4	1.80	3.31	12.8	2.11	3.85	10.6	2.35	4.15									
75	57.1	1.25	1.56	32.5	1.47	2.33	23.7	1.62	2.90	18.6	1.80	3.34	13.6	2.07	3.95	11.3	2.33	4.22									
80	60.9	1.25	1.56	34.7	1.48	2.32	25.3	1.63	2.89	19.8	1.79	3.35	14.5	2.07	3.95	12.0	2.31	4.28									
90	68.4	1.25	1.56	38.9	1.47	2.34	28.4	1.62	2.91	22.2	1.78	3.39	16.3	2.07	3.97	13.4	2.28	4.38	11.1	2.62	4.59						
100	75.9	1.25	1.56	43.2	1.47	2.34	31.5	1.62	2.92	24.7	1.79	3.37	18.1	2.07	3.98	14.9	2.28	4.37	12.2	2.56	4.75						
110	83.4	1.25	1.57	47.5	1.47	2.34	34.7	1.63	2.90	27.1	1.78	3.40	19.8	2.04	4.04	16.3	2.26	4.45	13.4	2.55	4.78						
120	90.8	1.25	1.57	51.8	1.47	2.34	37.8	1.62	2.91	29.6	1.79	3.38	21.6	2.05	4.04	17.8	2.26	4.43	14.6	2.54	4.80	12.1	2.85	5.16			
130	98.3	1.25	1.57	56.0	1.47	2.35	40.9	1.62	2.92	32.0	1.78	3.40	23.4	2.05	4.04	19.2	2.24	4.49	15.7	2.51	4.91	13.0	2.81	5.29			
140	105.7	1.25	1.57	60.3	1.47	2.35	44.0	1.62	2.92	34.4	1.78	3.41	25.1	2.03	4.09	20.7	2.25	4.48	16.9	2.51	4.92	14.0	2.81	5.29			
150	113.1	1.25	1.58	64.5	1.47	2.36	47.1	1.62	2.93	36.8	1.77	3.43	26.9	2.04	4.08	22.1	2.23	4.52	18.1	2.50	4.92	15.0	2.81	5.30			
160	120.5	1.25	1.58	68.8	1.47	2.35	50.2	1.62	2.93	39.3	1.78	3.41	28.7	2.04	4.07	23.6	2.24	4.50	19.3	2.50	4.93	15.9	2.77	5.40	13.1	3.13	5.80
170	127.9	1.25	1.58	73.0	1.47	2.36	53.3	1.62	2.93	41.7	1.78	3.42	30.4	2.03	4.11	25.0	2.23	4.54	20.4	2.48	5.00	16.9	2.78	5.39	13.9	3.12	5.83
180	135.2	1.25	1.58	77.2	1.47	2.36	56.4	1.62	2.93	44.1	1.78	3.43	32.2	2.03	4.10	26.5	2.24	4.52	21.6	2.48	5.00	17.8	2.75	5.48	14.7	3.11	5.85
190	142.6	1.25	1.58	81.5	1.47	2.36	59.5	1.62	2.93	46.5	1.77	3.43	34.0	2.04	4.09	27.9	2.23	4.56	22.8	2.48	5.00	18.8	2.75	5.46	15.5	3.11	5.87
200	149.9	1.25	1.58	85.7	1.47	2.36	62.5	1.62	2.95	48.9	1.77	3.44	35.7	2.03	4.12	29.4	2.23	4.54	24.0	2.49	4.99	19.7	2.73	5.54	16.3	3.10	5.88
220	164.7	1.25	1.58	94.2	1.47	2.36	68.7	1.62	2.95	53.8	1.78	3.43	39.3	2.03	4.11	32.3	2.23	4.55	26.3	2.47	5.05	21.7	2.74	5.52	17.9	3.09	5.92
240	179.4	1.25	1.59	102.6	1.47	2.37	74.9	1.62	2.95	58.6	1.77	3.44	42.8	2.03	4.12	35.2	2.23	4.56	28.7	2.47	5.04	23.6	2.72	5.57	19.4	3.05	6.04
260	194.1	1.25	1.59	111.1	1.47	2.37	81.1	1.62	2.95	63.5	1.78	3.44	46.3	2.02	4.14	38.1	2.23	4.57	31.0	2.46	5.09	25.5	2.71	5.61	21.0	3.05	6.05
280	208.8	1.25	1.59	119.5	1.47	2.37	87.3	1.62	2.95	68.3	1.77	3.44	49.9	2.03	4.12	41.0	2.22	4.58	33.4	2.46	5.08	27.4	2.70	5.65	22.6	3.04	6.07
300	223.5	1.26	1.59	127.9	1.47	2.37	93.4	1.62	2.96	73.1	1.77	3.45	53.4	2.03	4.13	43.9	2.22	4.58	35.8	2.47	5.07	29.4	2.71	5.62	24.2	3.04	6.08

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 3 of 14)

4-28487 5-68

V1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V2 for **RETARDANCE "C"**.

Grade 1.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.4	1.13	1.47	8.4	1.30	2.03																					
20	17.8	1.12	1.49	11.1	1.27	2.10	7.6	1.52	2.55																		
25	22.2	1.11	1.50	13.9	1.27	2.09	9.4	1.49	2.64	7.6	1.62	2.99															
30	26.6	1.11	1.50	16.6	1.26	2.13	11.2	1.46	2.71	9.1	1.61	3.03															
35	30.9	1.11	1.52	19.3	1.25	2.15	13.0	1.45	2.75	10.5	1.57	3.14	8.0	1.80	3.59												
40	35.3	1.11	1.52	22.1	1.26	2.13	14.8	1.44	2.79	12.0	1.57	3.14	9.1	1.78	3.65												
45	39.7	1.11	1.52	24.8	1.25	2.15	16.7	1.45	2.76	13.4	1.55	3.21	10.2	1.76	3.70												
50	44.0	1.11	1.52	27.5	1.25	2.16	18.5	1.44	2.79	14.9	1.55	3.21	11.3	1.75	3.74	8.7	2.02	4.20									
55	48.3	1.11	1.53	30.2	1.25	2.16	20.3	1.43	2.80	16.3	1.54	3.26	12.4	1.75	3.76	9.5	1.99	4.30									
60	52.7	1.11	1.52	32.9	1.25	2.17	22.1	1.43	2.82	17.8	1.54	3.25	13.5	1.74	3.79	10.4	2.01	4.26									
65	57.0	1.11	1.53	35.6	1.25	2.17	23.9	1.43	2.83	19.2	1.53	3.29	14.6	1.73	3.81	11.2	1.98	4.33	9.3	2.22	4.66						
70	61.3	1.11	1.53	38.3	1.25	2.17	25.7	1.43	2.84	20.7	1.53	3.27	15.6	1.71	3.90	12.0	1.96	4.40	10.0	2.21	4.69						
75	65.6	1.11	1.53	41.0	1.25	2.18	27.5	1.42	2.85	22.1	1.53	3.31	16.7	1.71	3.90	12.8	1.95	4.46	10.7	2.21	4.71						
80	69.8	1.11	1.54	43.7	1.25	2.18	29.3	1.42	2.85	23.6	1.53	3.29	17.8	1.71	3.91	13.7	1.96	4.42	11.3	2.16	4.85						
90	78.5	1.11	1.54	49.1	1.25	2.18	32.9	1.42	2.87	26.5	1.53	3.31	20.0	1.70	3.93	15.3	1.93	4.52	12.7	2.16	4.87	10.6	2.42	5.20			
100	87.1	1.11	1.54	54.5	1.25	2.18	36.6	1.43	2.85	29.4	1.52	3.32	22.2	1.70	3.94	17.0	1.93	4.52	14.1	2.15	4.89	11.7	2.39	5.31			
110	95.6	1.11	1.54	59.9	1.25	2.18	40.2	1.42	2.86	32.3	1.52	3.33	24.4	1.70	3.94	18.7	1.93	4.52	15.4	2.12	5.00	12.9	2.40	5.28	11.1	2.59	5.67
120	104.2	1.11	1.54	65.2	1.25	2.19	43.8	1.42	2.87	35.2	1.52	3.33	26.6	1.70	3.95	20.3	1.92	4.59	16.8	2.12	5.00	14.0	2.37	5.36	12.1	2.59	5.69
130	112.7	1.11	1.55	70.6	1.25	2.19	47.4	1.42	2.87	38.1	1.52	3.34	28.8	1.70	3.95	22.0	1.92	4.58	18.2	2.13	5.00	15.1	2.35	5.44	13.0	2.55	5.83
140	121.2	1.11	1.55	76.0	1.25	2.19	51.0	1.42	2.87	41.0	1.52	3.34	30.9	1.69	3.99	23.7	1.92	4.57	19.6	2.13	5.00	16.2	2.34	5.50	14.0	2.55	5.83
150	129.7	1.11	1.55	81.3	1.25	2.19	54.6	1.42	2.87	43.9	1.52	3.34	33.1	1.69	3.99	25.3	1.91	4.62	20.9	2.11	5.07	17.4	2.35	5.46	15.0	2.55	5.84
160	138.1	1.11	1.55	86.6	1.25	2.20	58.2	1.42	2.88	46.8	1.52	3.34	35.3	1.69	3.99	27.0	1.91	4.61	22.3	2.11	5.06	18.5	2.33	5.51	15.9	2.52	5.95
170	146.6	1.11	1.55	91.9	1.25	2.20	61.7	1.42	2.89	49.7	1.52	3.34	37.5	1.69	3.99	28.7	1.92	4.60	23.7	2.11	5.05	19.6	2.32	5.56	16.9	2.52	5.94
180	155.0	1.11	1.55	97.2	1.25	2.20	65.3	1.42	2.89	52.5	1.52	3.36	39.6	1.69	4.01	30.3	1.91	4.63	25.0	2.10	5.10	20.7	2.31	5.60	17.9	2.52	5.93
190	163.4	1.11	1.55	102.5	1.25	2.20	68.9	1.42	2.89	55.4	1.52	3.36	41.8	1.69	4.01	32.0	1.91	4.62	26.4	2.10	5.09	21.9	2.32	5.56	18.8	2.50	6.02
200	171.7	1.11	1.56	107.8	1.25	2.20	72.4	1.42	2.90	58.3	1.52	3.35	44.0	1.69	4.00	33.6	1.91	4.65	27.8	2.11	5.08	23.0	2.32	5.59	19.8	2.50	6.01
220	188.7	1.11	1.56	118.4	1.25	2.21	79.6	1.42	2.89	64.0	1.52	3.37	48.4	1.70	4.00	37.0	1.91	4.63	30.5	2.10	5.12	25.3	2.32	5.59	21.7	2.48	6.08
240	205.5	1.11	1.56	129.0	1.25	2.21	86.7	1.42	2.90	69.8	1.52	3.37	52.7	1.69	4.01	40.3	1.91	4.65	33.3	2.10	5.11	27.5	2.30	5.65	23.6	2.47	6.13
260	222.4	1.11	1.56	139.6	1.25	2.21	93.9	1.42	2.90	75.5	1.52	3.38	57.1	1.69	4.01	43.6	1.91	4.66	36.0	2.10	5.14	29.8	2.30	5.64	25.6	2.48	6.11
280	239.1	1.11	1.56	150.2	1.25	2.22	101.0	1.42	2.91	81.3	1.52	3.37	61.4	1.69	4.02	46.9	1.90	4.68	38.8	2.10	5.12	32.1	2.31	5.63	27.5	2.47	6.15
300	255.9	1.11	1.56	160.8	1.25	2.22	108.1	1.42	2.91	87.0	1.52	3.38	65.7	1.69	4.03	50.3	1.91	4.66	41.5	2.10	5.14	34.3	2.30	5.68	29.5	2.48	6.12

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 4 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 1.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	15.3	1.00	1.45	9.8	1.15	1.95	6.6	1.37	2.44																		
20	20.4	1.00	1.45	12.9	1.12	2.04	8.7	1.33	2.55	6.6	1.49	2.98															
25	25.4	0.99	1.47	16.1	1.12	2.05	10.8	1.31	2.61	8.2	1.47	3.06	6.7	1.62	3.38												
30	30.5	1.00	1.46	19.3	1.12	2.06	12.9	1.30	2.66	9.7	1.43	3.20	7.9	1.56	3.58												
35	35.5	0.99	1.47	22.5	1.12	2.06	15.0	1.29	2.68	11.3	1.42	3.22	9.2	1.55	3.62	7.2	1.78	4.02									
40	40.5	0.99	1.47	25.7	1.12	2.06	17.1	1.28	2.70	12.9	1.42	3.24	10.5	1.55	3.64	8.2	1.77	4.07									
45	45.5	0.99	1.48	28.8	1.11	2.08	19.2	1.28	2.72	14.4	1.40	3.31	11.7	1.52	3.75	9.1	1.72	4.25									
50	50.4	0.99	1.49	32.0	1.12	2.08	21.3	1.28	2.73	16.0	1.40	3.31	13.0	1.52	3.75	10.1	1.71	4.27	8.3	1.95	4.57						
55	55.4	0.99	1.48	35.1	1.11	2.09	23.4	1.28	2.74	17.6	1.40	3.31	14.3	1.52	3.75	11.1	1.71	4.29	9.1	1.93	4.63						
60	60.3	0.99	1.49	38.3	1.12	2.09	25.5	1.28	2.74	19.1	1.39	3.36	15.6	1.52	3.75	12.1	1.71	4.30	9.9	1.92	4.67						
65	65.2	0.99	1.49	41.4	1.11	2.10	27.6	1.28	2.74	20.7	1.39	3.35	16.8	1.51	3.81	13.0	1.68	4.41	10.6	1.88	4.84	8.7	2.18	5.06			
70	70.1	0.99	1.50	44.6	1.12	2.09	29.7	1.28	2.75	22.3	1.39	3.35	18.1	1.51	3.80	14.0	1.68	4.41	11.4	1.87	4.86	9.3	2.15	5.18			
75	75.0	0.99	1.50	47.7	1.12	2.09	31.8	1.28	2.75	23.8	1.39	3.38	19.4	1.51	3.80	15.0	1.68	4.40	12.2	1.87	4.88	9.9	2.12	5.28			
80	79.9	0.99	1.50	50.8	1.12	2.10	33.8	1.27	2.77	25.4	1.39	3.37	20.6	1.50	3.84	16.0	1.69	4.40	13.0	1.87	4.89	10.5	2.10	5.37	9.2	2.33	5.51
90	89.7	0.99	1.50	5 .1	1.12	2.10	38.0	1.27	2.77	28.5	1.38	3.39	23.2	1.51	3.83	17.9	1.67	4.48	14.6	1.86	4.92	11.8	2.09	5.40	10.3	2.31	5.60
100	99.6	0.99	1.50	63.3	1.11	2.11	42.2	1.27	2.77	31.7	1.39	3.38	25.7	1.50	3.86	19.9	1.67	4.47	16.2	1.85	4.94	13.1	2.09	5.42	11.4	2.29	5.68
110	109.4	0.99	1.50	69.6	1.12	2.11	46.4	1.27	2.77	34.8	1.39	3.39	28.3	1.50	3.85	21.9	1.67	4.46	17.8	1.85	4.96	14.4	2.09	5.43	12.4	2.24	5.88
120	119.1	0.99	1.51	75.8	1.12	2.11	50.5	1.27	2.78	37.9	1.38	3.41	30.8	1.50	3.87	23.8	1.66	4.51	19.3	1.83	5.05	15.6	2.06	5.55	13.5	2.23	5.91
130	128.9	1.00	1.51	82.0	1.12	2.11	54.7	1.27	2.78	41.1	1.39	3.39	33.3	1.49	3.89	25.8	1.67	4.50	20.9	1.83	5.05	16.9	2.06	5.55	14.6	2.22	5.95
140	138.6	1.00	1.51	88.2	1.12	2.12	58.8	1.27	2.79	44.2	1.39	3.40	35.9	1.50	3.87	27.8	1.67	4.48	22.5	1.83	5.06	18.2	2.06	5.55	15.7	2.22	5.97
150	148.2	1.00	1.51	94.4	1.12	2.12	63.0	1.27	2.78	47.3	1.39	3.41	38.4	1.50	3.88	29.7	1.66	4.52	24.1	1.83	5.06	19.4	2.04	5.63	16.8	2.21	6.00
160	157.9	1.00	1.51	100.6	1.12	2.12	67.1	1.27	2.79	50.4	1.39	3.41	40.9	1.50	3.89	31.7	1.67	4.51	25.7	1.83	5.06	20.7	2.05	5.62	17.9	2.21	6.01
170	167.5	1.00	1.51	106.7	1.12	2.12	71.2	1.27	2.79	53.5	1.39	3.41	43.4	1.49	3.90	33.6	1.66	4.53	27.3	1.83	5.06	22.0	2.05	5.62	19.0	2.21	6.03
180	177.1	1.00	1.51	112.9	1.12	2.12	75.3	1.27	2.80	56.6	1.39	3.42	46.0	1.50	3.88	35.6	1.67	4.52	28.9	1.84	5.05	23.3	2.05	5.61	20.1	2.21	6.04
190	186.6	1.00	1.52	119.0	1.12	2.12	79.4	1.27	2.80	59.7	1.39	3.42	48.5	1.50	3.89	37.5	1.66	4.54	30.4	1.83	5.10	24.5	2.04	5.67	21.2	2.20	6.05
200	196.1	1.00	1.52	125.1	1.12	2.13	83.5	1.27	2.80	62.8	1.39	3.42	51.0	1.50	3.90	39.5	1.67	4.52	32.0	1.83	5.09	25.8	2.04	5.66	22.3	2.20	6.06
220	215.4	1.00	1.52	137.4	1.12	2.13	91.8	1.27	2.80	69.0	1.39	3.42	56.0	1.50	3.91	43.4	1.67	4.53	35.2	1.83	5.09	28.3	2.03	5.70	24.5	2.20	6.08
240	234.7	1.00	1.52	149.8	1.12	2.13	100.0	1.27	2.81	75.2	1.39	3.43	61.1	1.50	3.90	47.3	1.67	4.54	38.4	1.83	5.09	30.9	2.04	5.68	26.7	2.20	6.10
260	253.8	1.00	1.52	162.0	1.12	2.13	108.2	1.27	2.81	81.4	1.39	3.43	66.1	1.50	3.91	51.2	1.66	4.55	41.5	1.83	5.12	33.4	2.03	5.72	28.8	2.18	6.18
280	273.0	1.00	1.52	174.3	1.12	2.13	116.4	1.27	2.81	87.6	1.39	3.43	71.1	1.50	3.92	55.1	1.67	4.55	44.7	1.83	5.11	36.0	2.03	5.70	31.0	2.18	6.18
300	292.0	1.00	1.53	186.5	1.12	2.14	124.6	1.27	2.82	93.7	1.39	3.44	76.2	1.50	3.91	59.0	1.67	4.55	47.8	1.82	5.13	38.5	2.03	5.73	33.2	2.18	6.19

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 5 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 1.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	17.0	0.92	1.42	11.3	1.05	1.86	7.6	1.20	2.41																		
20	22.7	0.92	1.41	14.9	1.03	1.93	10.0	1.17	2.53	7.0	1.40	3.01	5.7	1.52	3.39												
25	28.3	0.92	1.42	18.6	1.03	1.94	12.4	1.15	2.59	8.6	1.35	3.19	7.0	1.46	3.60												
30	33.9	0.92	1.43	22.3	1.03	1.94	14.9	1.15	2.59	10.3	1.34	3.22	8.4	1.46	3.62	6.9	1.59	4.03									
35	39.5	0.92	1.43	26.0	1.03	1.95	17.3	1.14	2.62	11.9	1.31	3.32	9.7	1.43	3.74	8.0	1.56	4.13									
40	45.0	0.92	1.44	29.7	1.03	1.94	19.8	1.15	2.61	13.6	1.31	3.32	11.1	1.43	3.73	9.1	1.55	4.20	7.1	1.79	4.64						
45	50.5	0.92	1.44	33.3	1.02	1.96	22.2	1.14	2.63	15.2	1.30	3.39	12.4	1.41	3.81	10.2	1.54	4.25	8.0	1.79	4.63						
50	56.1	0.92	1.44	37.0	1.03	1.95	24.6	1.14	2.65	16.9	1.30	3.38	13.7	1.39	3.88	11.3	1.53	4.29	8.8	1.75	4.78						
55	61.5	0.92	1.45	40.6	1.02	1.96	27.1	1.14	2.64	18.6	1.30	3.37	15.1	1.40	3.86	12.4	1.52	4.32	9.6	1.73	4.91	8.2	1.93	5.14			
60	67.0	0.92	1.45	44.2	1.02	1.97	29.5	1.14	2.65	20.2	1.29	3.41	16.4	1.39	3.91	13.5	1.52	4.35	10.5	1.73	4.88	8.9	1.91	5.23			
65	72.5	0.92	1.45	47.8	1.02	1.98	31.9	1.14	2.66	21.9	1.30	3.40	17.8	1.40	3.88	14.6	1.51	4.37	11.3	1.71	4.97	9.6	1.89	5.30			
70	77.9	0.92	1.45	51.4	1.02	1.98	34.3	1.14	2.66	23.5	1.29	3.43	19.1	1.39	3.92	15.7	1.51	4.39	12.2	1.72	4.94	10.3	1.88	5.36	8.8	2.12	5.55
75	83.3	0.92	1.46	55.0	1.02	1.98	36.7	1.14	2.67	25.2	1.29	3.42	20.5	1.40	3.89	16.8	1.51	4.40	13.0	1.70	5.02	11.0	1.87	5.41	9.4	2.10	5.61
80	88.7	0.92	1.46	58.6	1.02	1.98	39.1	1.14	2.67	26.8	1.29	3.44	21.8	1.39	3.93	17.9	1.50	4.41	13.9	1.71	4.98	11.7	1.86	5.46	9.9	2.05	5.83
90	99.6	0.92	1.46	65.8	1.02	1.99	44.0	1.14	2.66	30.1	1.29	3.46	24.5	1.39	3.93	20.1	1.50	4.43	15.6	1.71	5.02	13.2	1.87	5.42	11.1	2.04	5.90
100	110.5	0.92	1.46	73.0	1.02	1.99	48.8	1.14	2.67	33.4	1.29	3.47	27.2	1.39	3.94	22.3	1.50	4.45	17.3	1.70	5.05	14.6	1.85	5.50	12.3	2.03	5.95
110	121.4	0.92	1.46	80.2	1.02	1.99	53.6	1.14	2.68	36.7	1.28	3.47	29.9	1.39	3.94	24.5	1.50	4.46	19.0	1.70	5.07	16.0	1.84	5.56	13.5	2.02	6.00
120	132.2	0.92	1.46	87.3	1.02	2.00	58.4	1.14	2.68	40.0	1.28	3.48	32.6	1.39	3.95	26.7	1.49	4.47	20.7	1.69	5.09	17.5	1.85	5.52	14.7	2.01	6.03
130	142.9	0.92	1.47	94.5	1.02	2.00	63.2	1.14	2.68	43.3	1.29	3.48	35.3	1.39	3.94	28.9	1.49	4.48	22.4	1.69	5.10	18.9	1.84	5.57	15.9	2.00	6.06
140	153.6	0.92	1.47	101.6	1.02	2.00	68.0	1.14	2.69	46.6	1.29	3.48	37.9	1.38	3.97	31.1	1.49	4.48	24.0	1.68	5.18	20.3	1.83	5.61	17.1	2.00	6.08
150	164.3	0.92	1.47	108.7	1.03	2.00	72.8	1.14	2.68	49.9	1.29	3.48	40.6	1.39	3.97	33.3	1.49	4.49	25.7	1.68	5.18	21.7	1.82	5.64	18.3	2.00	6.10
160	175.0	0.92	1.47	115.7	1.02	2.01	77.6	1.14	2.68	53.2	1.29	3.48	43.3	1.39	3.97	35.5	1.50	4.49	27.4	1.68	5.19	23.2	1.83	5.60	19.5	1.99	6.12
170	185.6	0.92	1.48	122.8	1.03	2.01	82.3	1.14	2.69	56.4	1.29	3.49	45.9	1.38	3.99	37.7	1.50	4.49	29.1	1.68	5.19	24.6	1.83	5.63	20.7	1.99	6.13
180	196.2	0.92	1.48	129.8	1.02	2.01	87.1	1.14	2.69	59.7	1.29	3.49	48.6	1.39	3.98	39.8	1.49	4.52	30.8	1.68	5.19	26.0	1.82	5.66	21.9	1.99	6.14
190	206.7	0.92	1.48	136.8	1.03	2.02	91.8	1.14	2.69	62.9	1.29	3.50	51.3	1.39	3.97	42.0	1.49	4.52	32.5	1.68	5.18	27.4	1.82	5.68	23.1	1.99	6.15
200	217.2	0.92	1.48	143.8	1.03	2.02	96.5	1.14	2.70	66.2	1.29	3.49	53.9	1.39	3.99	44.2	1.49	4.51	34.2	1.68	5.18	28.9	1.83	5.64	24.3	1.99	6.16
220	238.5	0.92	1.48	157.9	1.03	2.02	106.0	1.14	2.70	72.7	1.29	3.50	59.3	1.39	3.98	48.6	1.50	4.51	37.6	1.68	5.19	31.7	1.82	5.68	26.7	1.99	6.18
240	259.7	0.92	1.49	172.0	1.03	2.02	115.6	1.15	2.70	79.3	1.29	3.50	64.6	1.39	3.99	53.0	1.50	4.51	40.9	1.67	5.23	34.6	1.82	5.67	29.1	1.98	6.19
260	280.9	0.92	1.49	186.1	1.03	2.03	125.0	1.15	2.71	85.8	1.29	3.51	69.9	1.39	3.99	57.3	1.49	4.53	44.3	1.68	5.22	37.4	1.82	5.70	31.5	1.98	6.20
280	302.0	0.92	1.49	200.1	1.03	2.03	134.5	1.15	2.71	92.3	1.29	3.51	75.2	1.39	4.00	61.7	1.50	4.53	47.7	1.68	5.22	40.3	1.82	5.69	33.9	1.98	6.21
300	323.0	0.93	1.49	214.1	1.03	2.03	143.9	1.15	2.71	98.8	1.29	3.51	80.5	1.39	4.00	66.0	1.49	4.54	51.1	1.68	5.21	43.1	1.82	5.71	36.3	1.98	6.21

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 6 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 1.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	18.5	0.87	1.38	12.1	0.97	1.89	8.5	1.08	2.40	5.9	1.28	2.92															
20	24.5	0.86	1.41	16.1	0.96	1.91	11.3	1.07	2.43	7.8	1.25	3.03	6.5	1.34	3.38												
25	30.6	0.86	1.41	20.1	0.96	1.91	14.1	1.07	2.45	9.7	1.23	3.09	8.1	1.33	3.43	6.6	1.46	3.81									
30	36.7	0.86	1.40	24.1	0.96	1.92	16.8	1.06	2.50	11.6	1.22	3.13	9.6	1.29	3.57	7.8	1.41	4.01									
35	42.7	0.86	1.41	28.1	0.96	1.92	19.6	1.06	2.50	13.4	1.20	3.23	11.2	1.29	3.58	9.1	1.41	4.02	7.1	1.59	4.57						
40	48.7	0.86	1.42	32.0	0.96	1.93	22.4	1.06	2.50	15.3	1.20	3.24	12.7	1.27	3.67	10.3	1.38	4.15	8.1	1.58	4.61						
45	54.7	0.86	1.42	36.0	0.96	1.93	25.1	1.05	2.53	17.2	1.20	3.24	14.3	1.28	3.66	11.6	1.39	4.14	9.1	1.57	4.64	7.5	1.73	5.12			
50	60.7	0.86	1.42	39.9	0.96	1.94	27.9	1.06	2.52	19.1	1.20	3.25	15.8	1.26	3.72	12.8	1.37	4.22	10.0	1.54	4.80	8.3	1.71	5.20			
55	66.6	0.86	1.42	43.8	0.96	1.94	30.6	1.05	2.53	21.0	1.20	3.25	17.4	1.27	3.70	14.1	1.37	4.21	11.0	1.54	4.80	9.1	1.70	5.25	7.5	1.91	5.65
60	72.5	0.86	1.43	47.7	0.96	1.95	33.3	1.05	2.55	22.8	1.19	3.29	18.9	1.26	3.75	15.4	1.38	4.19	12.0	1.54	4.81	9.9	1.69	5.30	8.2	1.92	5.63
65	78.4	0.86	1.43	51.6	0.96	1.95	36.1	1.06	2.54	24.7	1.19	3.28	20.5	1.26	3.73	16.6	1.37	4.25	12.9	1.52	4.92	10.7	1.68	5.34	8.8	1.88	5.79
70	84.3	0.86	1.43	55.5	0.96	1.95	38.8	1.05	2.54	26.6	1.19	3.28	22.0	1.26	3.76	17.9	1.37	4.23	13.9	1.52	4.91	11.5	1.68	5.38	9.5	1.89	5.76
75	90.2	0.86	1.43	59.4	0.96	1.95	41.5	1.05	2.55	28.5	1.20	3.27	23.6	1.26	3.74	19.1	1.36	4.28	14.9	1.52	4.90	12.3	1.67	5.40	10.1	1.87	5.89
80	96.0	0.86	1.43	63.2	0.96	1.96	44.2	1.05	2.56	30.3	1.19	3.30	25.1	1.26	3.77	20.4	1.37	4.25	15.9	1.53	4.89	13.1	1.67	5.43	10.8	1.88	5.85
90	107.8	0.86	1.44	71.0	0.96	1.96	49.7	1.05	2.55	34.1	1.19	3.29	28.2	1.26	3.78	22.9	1.37	4.28	17.8	1.51	4.96	14.7	1.66	5.47	12.1	1.86	5.93
100	119.5	0.86	1.44	78.8	0.96	1.96	55.1	1.05	2.56	37.8	1.19	3.31	31.3	1.26	3.79	25.4	1.36	4.30	19.8	1.52	4.94	16.3	1.65	5.51	13.4	1.85	5.99
110	131.2	0.86	1.44	86.5	0.96	1.97	60.5	1.05	2.57	41.5	1.19	3.32	34.4	1.26	3.79	27.9	1.36	4.31	21.7	1.51	4.99	17.9	1.65	5.53	14.7	1.84	6.05
120	142.9	0.86	1.44	94.2	0.96	1.97	65.9	1.05	2.58	45.3	1.19	3.31	37.5	1.26	3.79	30.4	1.36	4.32	23.7	1.51	4.97	19.5	1.65	5.55	16.0	1.83	6.09
130	154.5	0.86	1.45	101.9	0.96	1.97	71.3	1.05	2.58	49.0	1.19	3.31	40.6	1.26	3.79	32.9	1.36	4.33	25.6	1.51	5.01	21.1	1.65	5.57	17.3	1.82	6.12
140	166.1	0.87	1.45	109.6	0.96	1.97	76.7	1.05	2.58	52.7	1.19	3.32	43.7	1.26	3.79	35.4	1.36	4.33	27.6	1.51	4.99	22.7	1.64	5.58	18.6	1.82	6.15
150	177.6	0.87	1.45	117.2	0.96	1.98	82.1	1.05	2.58	56.4	1.19	3.32	46.8	1.26	3.79	37.9	1.36	4.33	29.5	1.51	5.02	24.3	1.64	5.59	19.9	1.82	6.17
160	189.1	0.87	1.45	124.8	0.96	1.98	87.5	1.06	2.58	60.1	1.19	3.33	49.8	1.26	3.81	40.4	1.36	4.33	31.4	1.50	5.04	25.9	1.64	5.60	21.3	1.83	6.10
170	200.5	0.87	1.45	132.4	0.96	1.98	92.8	1.05	2.58	63.7	1.19	3.34	52.9	1.26	3.80	42.9	1.36	4.33	33.4	1.51	5.02	27.5	1.64	5.60	22.6	1.83	6.13
180	211.9	0.87	1.46	140.0	0.96	1.98	98.1	1.05	2.59	67.4	1.19	3.34	55.9	1.26	3.82	45.4	1.36	4.33	35.3	1.51	5.04	29.1	1.64	5.61	23.9	1.83	6.14
190	223.3	0.87	1.46	147.5	0.96	1.99	103.4	1.05	2.59	71.1	1.19	3.34	59.0	1.26	3.81	47.8	1.36	4.36	37.2	1.50	5.06	30.7	1.64	5.61	25.2	1.82	6.16
200	234.6	0.87	1.46	155.1	0.97	1.99	108.7	1.06	2.60	74.7	1.19	3.35	62.0	1.26	3.82	50.3	1.36	4.35	39.2	1.51	5.03	32.3	1.64	5.61	26.5	1.82	6.17
220	257.6	0.87	1.46	170.3	0.96	1.99	119.4	1.06	2.60	82.1	1.19	3.35	68.1	1.26	3.83	55.3	1.36	4.35	43.1	1.51	5.03	35.5	1.64	5.62	29.1	1.82	6.20
240	280.4	0.87	1.47	185.5	0.97	1.99	130.1	1.06	2.60	89.5	1.19	3.35	74.3	1.26	3.82	60.3	1.36	4.35	46.9	1.51	5.06	38.7	1.64	5.62	31.7	1.81	6.22
260	303.2	0.87	1.47	200.6	0.97	2.00	140.8	1.06	2.60	96.9	1.19	3.35	80.4	1.26	3.82	65.2	1.36	4.37	50.8	1.51	5.06	41.9	1.64	5.63	34.3	1.81	6.24
280	326.0	0.87	1.47	215.7	0.97	2.00	151.4	1.06	2.61	104.2	1.19	3.36	86.5	1.26	3.83	70.2	1.36	4.36	54.7	1.51	5.05	45.1	1.64	5.63	36.9	1.81	6.25
300	348.6	0.87	1.47	230.8	0.97	2.00	162.0	1.06	2.61	111.5	1.19	3.36	92.5	1.26	3.84	75.1	1.36	4.37	58.5	1.51	5.07	48.3	1.65	5.63	39.5	1.81	6.26

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 7 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 2.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	20.8	0.81	1.32	12.8	0.91	1.90	9.3	1.00	2.37	6.7	1.15	2.85															
20	27.6	0.80	1.33	17.1	0.91	1.89	12.3	0.99	2.43	8.8	1.12	3.00	6.5	1.29	3.51	5.4	1.41	3.84									
25	34.5	0.81	1.33	21.3	0.91	1.91	15.4	0.99	2.43	11.0	1.11	3.01	8.0	1.25	3.69	6.7	1.38	3.96									
30	41.3	0.81	1.34	25.5	0.91	1.92	18.4	0.98	2.46	13.2	1.11	3.02	9.6	1.24	3.71	7.9	1.33	4.20	6.6	1.49	4.48						
35	48.0	0.80	1.35	29.7	0.91	1.93	21.5	0.99	2.44	15.3	1.10	3.08	11.1	1.22	3.82	9.2	1.33	4.23	7.6	1.45	4.68						
40	54.8	0.80	1.34	33.9	0.91	1.93	24.5	0.95	2.46	17.5	1.10	3.07	12.7	1.22	3.81	10.5	1.32	4.26	8.7	1.45	4.67	7.2	1.65	4.96			
45	61.5	0.80	1.35	38.1	0.91	1.93	27.5	0.98	2.47	19.6	1.10	3.11	14.3	1.23	3.80	11.8	1.32	4.27	9.7	1.43	4.80	8.0	1.61	5.16			
50	68.2	0.80	1.35	42.3	0.91	1.93	30.5	0.98	2.48	21.8	1.10	3.09	15.8	1.22	3.86	13.1	1.32	4.28	10.8	1.43	4.78	8.8	1.57	5.33	7.5	1.74	5.64
55	74.9	0.81	1.35	46.4	0.91	1.94	33.5	0.98	2.48	23.9	1.09	3.12	17.4	1.22	3.84	14.4	1.32	4.29	11.8	1.42	4.87	9.7	1.58	5.30	8.2	1.72	5.75
60	81.5	0.81	1.36	50.6	0.91	1.93	36.5	0.98	2.49	26.1	1.10	3.10	18.9	1.21	3.89	15.6	1.30	4.38	12.9	1.42	4.84	10.6	1.59	5.28	9.0	1.74	5.65
65	88.1	0.81	1.36	54.7	0.91	1.94	39.5	0.98	2.49	28.2	1.10	3.12	20.5	1.22	3.87	16.9	1.30	4.38	13.9	1.41	4.92	11.4	1.56	5.40	9.7	1.73	5.74
70	94.7	0.81	1.36	58.8	0.91	1.94	42.5	0.98	2.49	30.3	1.09	3.14	22.0	1.21	3.90	18.2	1.31	4.37	15.0	1.42	4.89	12.3	1.57	5.37	10.4	1.71	5.82
75	101.2	0.81	1.36	62.9	0.91	1.94	45.5	0.99	2.49	32.4	1.09	3.15	23.6	1.22	3.88	19.5	1.31	4.37	16.0	1.41	4.95	13.1	1.55	5.46	11.1	1.70	5.89
80	107.8	0.81	1.36	67.0	0.91	1.95	48.4	0.98	2.50	34.6	1.10	3.13	25.1	1.21	3.91	20.7	1.30	4.42	17.1	1.41	4.91	14.0	1.56	5.43	11.8	1.69	5.95
90	121.0	0.81	1.37	75.2	0.91	1.95	54.4	0.98	2.50	38.8	1.09	3.15	28.2	1.21	3.92	23.3	1.30	4.41	19.2	1.41	4.94	15.7	1.55	5.48	13.3	1.69	5.92
100	134.2	0.81	1.37	83.4	0.91	1.96	60.4	0.99	2.50	43.1	1.10	3.15	31.3	1.21	3.93	25.9	1.30	4.40	21.3	1.41	4.96	17.4	1.55	5.52	14.7	1.68	6.02
110	147.3	0.81	1.37	91.6	0.91	1.96	66.3	0.98	2.51	47.4	1.10	3.15	34.4	1.21	3.93	28.4	1.30	4.44	23.4	1.40	4.98	19.1	1.54	5.55	16.2	1.68	5.99
120	160.3	0.81	1.38	99.8	0.91	1.96	72.2	0.98	2.51	51.6	1.10	3.16	37.5	1.21	3.93	31.0	1.30	4.42	25.5	1.40	4.99	20.8	1.54	5.58	17.6	1.67	6.06
130	173.3	0.81	1.38	107.9	0.91	1.96	78.1	0.98	2.51	55.8	1.09	3.17	40.6	1.21	3.93	33.5	1.30	4.45	27.6	1.40	5.00	22.5	1.53	5.60	19.1	1.68	6.03
140	186.3	0.81	1.38	116.0	0.91	1.97	84.0	0.99	2.52	60.1	1.10	3.16	43.6	1.21	3.96	36.0	1.29	4.47	29.7	1.40	5.00	24.2	1.53	5.62	20.5	1.67	6.08
150	199.2	0.81	1.38	124.1	0.91	1.97	89.9	0.99	2.52	64.3	1.10	3.16	46.7	1.21	3.96	38.6	1.30	4.45	31.8	1.40	5.00	25.9	1.53	5.63	21.9	1.66	6.13
160	212.0	0.81	1.38	132.1	0.91	1.97	95.7	0.99	2.52	68.5	1.10	3.17	49.8	1.21	3.95	41.1	1.30	4.47	33.8	1.40	5.05	27.6	1.53	5.64	23.4	1.67	6.09
170	224.8	0.81	1.39	140.2	0.91	1.97	101.6	0.99	2.52	72.7	1.10	3.17	52.8	1.21	3.97	43.6	1.30	4.48	35.9	1.40	5.05	29.3	1.53	5.65	24.8	1.66	6.13
180	237.5	0.81	1.39	148.2	0.91	1.98	107.4	0.99	2.53	76.8	1.10	3.18	55.9	1.21	3.96	46.2	1.30	4.46	38.0	1.40	5.04	31.0	1.53	5.65	26.3	1.67	6.10
190	250.2	0.81	1.39	156.1	0.91	1.98	113.2	0.99	2.53	81.0	1.10	3.18	58.9	1.21	3.97	48.7	1.30	4.47	40.1	1.40	5.04	32.7	1.53	5.65	27.7	1.67	6.13
200	262.8	0.81	1.39	164.1	0.91	1.98	119.0	0.99	2.53	85.2	1.10	3.18	61.9	1.21	3.98	51.2	1.30	4.48	42.2	1.40	5.03	34.4	1.53	5.66	29.1	1.66	6.16
220	288.5	0.81	1.40	180.2	0.91	1.99	130.7	0.99	2.54	93.6	1.10	3.18	68.1	1.21	3.97	56.3	1.30	4.48	46.3	1.40	5.06	37.8	1.53	5.67	32.0	1.66	6.16
240	314.1	0.81	1.40	196.2	0.91	1.99	142.4	0.99	2.54	102.0	1.10	3.19	74.2	1.21	3.98	61.3	1.30	4.50	50.5	1.40	5.06	41.2	1.53	5.68	34.9	1.66	6.16
260	339.5	0.81	1.40	212.2	0.91	1.99	154.0	0.99	2.54	110.3	1.10	3.20	80.3	1.21	3.98	66.4	1.30	4.49	54.7	1.40	5.05	44.6	1.53	5.68	37.8	1.66	6.16
280	364.9	0.81	1.40	228.2	0.92	1.99	165.6	0.99	2.55	118.7	1.10	3.19	86.3	1.21	4.00	71.4	1.30	4.50	58.8	1.40	5.07	48.0	1.53	5.68	40.6	1.66	6.20
300	390.2	0.81	1.40	244.1	0.92	2.00	177.2	0.99	2.55	127.0	1.10	3.20	92.4	1.21	4.00	76.4	1.30	4.51	63.0	1.40	5.06	51.4	1.53	5.68	43.5	1.66	6.19

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 8 of 14)

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V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 3.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	23.6	0.69	1.35	16.3	0.76	1.80	11.4	0.83	2.33	8.8	0.90	2.77	6.5	1.01	3.37	5.0	1.16	3.78									
20	31.4	0.69	1.36	21.7	0.76	1.81	15.2	0.83	2.34	11.7	0.90	2.81	8.6	0.99	3.48	6.6	1.13	3.94	5.9	1.19	4.17						
25	39.2	0.69	1.36	27.0	0.75	1.83	19.0	0.83	2.33	14.6	0.90	2.83	10.8	0.99	3.44	8.1	1.09	4.18	7.3	1.16	4.33	6.0	1.27	4.80			
30	46.9	0.69	1.37	32.4	0.75	1.82	22.7	0.83	2.36	17.4	0.88	2.89	12.9	0.98	3.49	9.7	1.08	4.22	8.7	1.15	4.44	7.1	1.24	5.03	5.8	1.41	5.37
35	54.6	0.69	1.37	37.7	0.75	1.83	26.4	0.83	2.38	20.3	0.89	2.88	15.0	0.98	3.53	11.3	1.08	4.25	10.1	1.13	4.51	8.3	1.24	5.02	6.7	1.38	5.55
40	62.2	0.69	1.37	43.0	0.75	1.83	30.2	0.83	2.37	23.2	0.89	2.88	17.1	0.98	3.55	12.9	1.08	4.26	11.5	1.13	4.57	9.4	1.22	5.17	7.6	1.36	5.70
45	69.9	0.70	1.37	48.3	0.75	1.83	33.9	0.83	2.37	26.0	0.88	2.90	19.2	0.97	3.57	14.5	1.08	4.27	12.9	1.12	4.61	10.6	1.22	5.14	8.5	1.34	5.81
50	77.4	0.69	1.38	53.5	0.75	1.84	37.6	0.83	2.38	28.9	0.89	2.89	21.3	0.97	3.58	16.0	1.06	4.36	14.3	1.12	4.63	11.7	1.21	5.24	9.4	1.33	5.90
55	85.0	0.70	1.38	58.7	0.75	1.85	41.2	0.83	2.40	31.7	0.89	2.91	23.4	0.97	3.58	17.6	1.06	4.35	15.7	1.11	4.66	12.9	1.21	5.20	10.4	1.35	5.80
60	92.5	0.70	1.38	64.0	0.75	1.84	44.9	0.83	2.40	34.5	0.88	2.92	25.5	0.97	3.59	19.2	1.07	4.35	17.1	1.11	4.67	14.0	1.20	5.28	11.3	1.34	5.87
65	99.9	0.69	1.39	69.1	0.75	1.85	48.6	0.83	2.39	37.3	0.88	2.93	27.6	0.97	3.59	20.8	1.07	4.34	18.5	1.11	4.69	15.2	1.21	5.24	12.2	1.33	5.93
70	107.3	0.69	1.39	74.3	0.75	1.86	52.2	0.83	2.40	40.1	0.88	2.93	29.7	0.98	3.59	22.3	1.06	4.39	19.9	1.11	4.69	16.3	1.20	5.30	13.1	1.32	5.98
75	114.7	0.70	1.39	79.4	0.75	1.86	55.8	0.83	2.41	42.9	0.88	2.94	31.8	0.98	3.59	23.9	1.06	4.38	21.3	1.11	4.70	17.5	1.21	5.26	14.0	1.32	6.02
80	122.1	0.70	1.40	84.5	0.75	1.87	59.4	0.83	2.42	45.7	0.88	2.94	33.9	0.98	3.58	25.5	1.07	4.36	22.7	1.11	4.70	18.6	1.20	5.31	15.0	1.33	5.94
90	137.0	0.70	1.40	94.9	0.75	1.87	66.7	0.83	2.42	51.4	0.89	2.93	38.0	0.97	3.61	28.6	1.06	4.40	25.5	1.11	4.72	20.9	1.20	5.33	16.8	1.32	6.01
100	151.8	0.70	1.40	105.2	0.75	1.87	74.0	0.83	2.42	57.0	0.89	2.94	42.2	0.98	3.61	31.7	1.06	4.42	28.3	1.11	4.73	23.2	1.20	5.34	18.6	1.31	6.08
110	166.6	0.70	1.41	115.5	0.75	1.87	81.3	0.83	2.42	62.6	0.89	2.95	46.4	0.98	3.61	34.9	1.06	4.40	31.0	1.10	4.78	25.5	1.20	5.34	20.5	1.32	6.04
120	181.3	0.70	1.41	125.7	0.75	1.88	88.5	0.83	2.43	68.2	0.89	2.95	50.5	0.98	3.62	38.0	1.06	4.42	33.8	1.11	4.78	27.7	1.19	5.40	22.3	1.32	6.08
130	195.9	0.70	1.41	135.9	0.76	1.88	95.7	0.83	2.43	73.7	0.89	2.96	54.6	0.98	3.63	41.1	1.06	4.43	36.6	1.11	4.77	30.0	1.19	5.40	24.2	1.32	6.04
140	210.5	0.70	1.41	146.1	0.76	1.88	102.8	0.83	2.44	79.3	0.89	2.96	58.8	0.98	3.62	44.2	1.06	4.44	39.4	1.11	4.77	32.3	1.20	5.39	26.0	1.32	6.08
150	225.0	0.70	1.42	156.2	0.76	1.89	110.0	0.83	2.44	84.8	0.89	2.96	62.9	0.98	3.63	47.3	1.06	4.44	42.1	1.11	4.80	34.6	1.20	5.38	27.8	1.31	6.11
160	239.4	0.70	1.42	166.2	0.76	1.89	117.1	0.83	2.45	90.3	0.89	2.97	67.0	0.98	3.63	50.4	1.06	4.45	44.9	1.11	4.79	36.8	1.19	5.42	29.6	1.31	6.13
170	253.7	0.70	1.42	176.2	0.76	1.90	124.2	0.83	2.45	95.8	0.89	2.97	71.1	0.98	3.64	53.5	1.06	4.45	47.7	1.11	4.78	39.1	1.20	5.41	31.5	1.32	6.09
180	268.0	0.70	1.43	186.2	0.76	1.90	131.2	0.83	2.46	101.3	0.89	2.97	75.2	0.98	3.64	56.6	1.06	4.45	50.4	1.11	4.80	41.3	1.19	5.44	33.3	1.32	6.11
190	282.2	0.70	1.43	196.1	0.76	1.90	138.3	0.83	2.46	106.7	0.89	2.98	79.2	0.98	3.65	59.7	1.07	4.45	53.1	1.11	4.81	43.6	1.20	5.42	35.1	1.32	6.12
200	296.3	0.70	1.43	206.0	0.76	1.90	145.3	0.83	2.46	112.2	0.89	2.98	83.3	0.98	3.65	62.7	1.06	4.47	55.9	1.11	4.80	45.8	1.19	5.45	36.9	1.32	6.14
220	325.1	0.70	1.44	226.1	0.76	1.91	159.5	0.83	2.47	123.2	0.89	2.98	91.5	0.98	3.65	68.9	1.06	4.47	61.4	1.11	4.81	50.4	1.20	5.43	40.6	1.32	6.12
240	353.8	0.70	1.44	246.2	0.76	1.91	173.7	0.83	2.47	134.2	0.89	2.99	99.7	0.98	3.65	75.1	1.07	4.47	66.9	1.11	4.81	54.9	1.20	5.44	44.2	1.32	6.15
260	382.4	0.70	1.44	266.1	0.76	1.92	187.8	0.83	2.48	145.1	0.89	2.99	107.8	0.98	3.67	81.3	1.07	4.47	72.4	1.11	4.82	59.4	1.20	5.45	47.8	1.31	6.17
280	410.8	0.70	1.45	286.0	0.76	1.92	201.9	0.83	2.48	156.0	0.89	3.00	116.0	0.98	3.66	87.4	1.07	4.48	77.9	1.11	4.82	63.9	1.20	5.46	51.5	1.32	6.15
300	439.0	0.70	1.45	305.8	0.76	1.92	215.9	0.83	2.49	166.9	0.89	3.00	124.1	0.98	3.67	93.6	1.07	4.47	83.3	1.11	4.83	68.4	1.20	5.46	55.1	1.32	6.17

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 9 of 14)

4-26467 5-88

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "C".

Grade 4.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	27.9	0.62	1.29	19.9	0.66	1.68	13.9	0.73	2.20	10.3	0.79	2.73	7.9	0.85	3.28	6.3	0.92	3.78	4.9	1.06	4.21						
20	37.1	0.62	1.29	26.5	0.66	1.69	18.5	0.72	2.21	13.7	0.78	2.76	10.5	0.84	3.33	8.4	0.92	3.81	6.4	1.01	4.52	5.5	1.09	4.88			
25	46.2	0.62	1.30	33.0	0.66	1.70	23.0	0.72	2.24	17.1	0.78	2.77	13.1	0.84	3.35	10.5	0.92	3.82	8.0	1.01	4.55	6.8	1.06	5.09	5.7	1.20	5.34
30	55.3	0.62	1.30	39.5	0.66	1.70	27.6	0.72	2.23	20.4	0.77	2.82	15.7	0.84	3.36	12.5	0.91	3.92	9.5	0.99	4.71	8.2	1.07	5.03	6.7	1.15	5.71
35	64.3	0.62	1.31	46.0	0.66	1.71	32.1	0.72	2.25	23.8	0.78	2.81	18.3	0.84	3.37	14.6	0.91	3.90	11.1	0.99	4.70	9.5	1.06	5.15	7.8	1.15	5.77
40	73.3	0.62	1.31	52.4	0.66	1.71	36.6	0.72	2.25	27.1	0.77	2.83	20.8	0.83	3.42	16.6	0.90	3.96	12.7	1.00	4.68	10.8	1.04	5.24	8.9	1.14	5.81
45	82.2	0.62	1.32	58.8	0.66	1.72	41.1	0.72	2.26	30.4	0.77	2.85	23.4	0.84	3.41	18.7	0.91	3.94	14.2	0.98	4.77	12.2	1.05	5.17	10.0	1.14	5.83
50	91.1	0.62	1.32	65.2	0.66	1.72	45.6	0.72	2.26	33.7	0.77	2.86	26.0	0.84	3.40	20.7	0.90	3.97	15.8	0.99	4.74	13.5	1.05	5.24	11.1	1.14	5.85
55	99.9	0.62	1.32	71.5	0.66	1.73	50.1	0.72	2.26	37.0	0.77	2.86	28.5	0.84	3.43	22.8	0.91	3.95	17.3	0.98	4.80	14.8	1.04	5.28	12.2	1.14	5.87
60	108.7	0.62	1.32	77.8	0.66	1.73	54.5	0.72	2.26	40.3	0.77	2.87	31.0	0.83	3.45	24.8	0.90	3.97	18.9	0.99	4.77	16.1	1.04	5.32	13.3	1.14	5.88
65	117.4	0.62	1.33	84.1	0.66	1.73	58.9	0.72	2.27	43.6	0.77	2.87	33.6	0.84	3.43	26.8	0.90	3.99	20.4	0.98	4.81	17.5	1.05	5.26	14.3	1.12	6.00
70	126.1	0.62	1.33	90.3	0.66	1.74	63.3	0.72	2.27	46.9	0.77	2.86	36.1	0.84	3.44	28.8	0.90	4.01	21.9	0.98	4.85	18.8	1.04	5.29	15.4	1.12	6.00
75	134.7	0.62	1.33	96.5	0.66	1.74	67.7	0.72	2.28	50.1	0.77	2.88	38.6	0.84	3.45	30.9	0.91	3.98	23.5	0.98	4.82	20.1	1.04	5.31	16.5	1.13	5.99
80	143.3	0.62	1.34	102.7	0.66	1.74	72.1	0.72	2.28	53.3	0.77	2.89	41.1	0.84	3.46	32.9	0.91	3.99	25.0	0.98	4.84	21.4	1.04	5.33	17.6	1.13	5.98
90	160.8	0.62	1.34	115.2	0.66	1.75	80.9	0.72	2.28	59.9	0.77	2.89	46.2	0.84	3.46	36.9	0.90	4.01	28.1	0.98	4.85	24.0	1.04	5.38	19.7	1.12	6.07
100	178.2	0.62	1.34	127.7	0.66	1.75	89.7	0.72	2.29	66.4	0.77	2.90	51.2	0.84	3.47	41.0	0.91	4.00	31.2	0.98	4.85	26.7	1.04	5.35	21.9	1.12	6.05
110	195.4	0.62	1.35	140.1	0.66	1.76	98.5	0.72	2.29	72.9	0.77	2.90	56.2	0.84	3.48	45.0	0.90	4.02	34.3	0.98	4.85	29.3	1.04	5.37	24.1	1.12	6.03
120	212.6	0.62	1.35	152.5	0.66	1.76	107.2	0.72	2.30	79.4	0.77	2.90	61.2	0.84	3.49	49.0	0.90	4.03	37.3	0.98	4.88	31.9	1.04	5.40	26.2	1.12	6.09
130	229.6	0.62	1.35	164.8	0.66	1.76	115.9	0.72	2.30	85.9	0.77	2.91	66.2	0.84	3.49	53.0	0.90	4.03	40.4	0.98	4.87	34.6	1.04	5.36	28.4	1.12	6.07
140	246.6	0.62	1.36	177.0	0.66	1.77	124.5	0.72	2.30	92.3	0.77	2.91	71.2	0.84	3.49	57.0	0.90	4.04	43.4	0.98	4.90	37.2	1.04	5.38	30.5	1.12	6.10
150	263.5	0.62	1.36	189.1	0.66	1.77	133.2	0.73	2.30	98.7	0.77	2.92	76.2	0.84	3.49	61.0	0.91	4.04	46.5	0.98	4.88	39.8	1.04	5.39	32.7	1.12	6.08
160	280.3	0.62	1.36	201.2	0.66	1.78	141.7	0.73	2.31	105.1	0.77	2.92	81.1	0.84	3.50	65.0	0.91	4.04	49.5	0.98	4.90	42.4	1.04	5.40	34.8	1.12	6.11
170	296.9	0.62	1.37	213.3	0.67	1.78	150.3	0.73	2.31	111.5	0.78	2.92	86.0	0.84	3.51	68.9	0.91	4.05	52.5	0.98	4.91	45.0	1.04	5.40	36.9	1.12	6.13
180	313.5	0.62	1.37	225.3	0.67	1.78	158.8	0.73	2.32	117.8	0.78	2.93	90.9	0.84	3.52	72.9	0.91	4.05	55.6	0.98	4.90	47.6	1.04	5.40	39.1	1.12	6.11
190	330.0	0.62	1.37	237.2	0.67	1.79	167.3	0.73	2.32	124.2	0.78	2.93	95.8	0.84	3.52	76.8	0.91	4.06	58.6	0.98	4.90	50.2	1.04	5.40	41.2	1.12	6.12
200	346.4	0.62	1.37	249.1	0.67	1.79	175.7	0.73	2.32	130.5	0.78	2.93	100.7	0.84	3.52	80.7	0.91	4.07	61.6	0.98	4.91	52.7	1.04	5.43	43.3	1.12	6.14
220	380.0	0.62	1.38	273.3	0.67	1.79	192.9	0.73	2.33	143.3	0.78	2.93	110.6	0.84	3.53	88.7	0.91	4.07	67.6	0.98	4.93	57.9	1.04	5.44	47.6	1.12	6.14
240	413.3	0.62	1.38	297.4	0.67	1.80	209.9	0.73	2.33	156.0	0.78	2.94	120.4	0.84	3.53	96.6	0.91	4.07	73.7	0.98	4.93	63.1	1.04	5.44	51.9	1.12	6.14
260	446.5	0.62	1.39	321.4	0.67	1.80	227.0	0.73	2.33	168.7	0.78	2.94	130.2	0.84	3.54	104.5	0.91	4.08	79.7	0.98	4.94	68.3	1.04	5.44	56.2	1.12	6.13
280	479.5	0.62	1.39	345.3	0.67	1.80	243.9	0.73	2.34	181.3	0.78	2.95	140.0	0.84	3.54	112.3	0.91	4.09	85.8	0.99	4.93	73.5	1.04	5.44	60.4	1.12	6.15
300	512.3	0.62	1.39	369.0	0.67	1.81	260.8	0.73	2.34	193.9	0.78	2.95	149.8	0.84	3.55	120.2	0.91	4.09	91.8	0.99	4.94	78.6	1.04	5.46	64.7	1.12	6.14

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 10 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 5.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	29.3	0.57	1.33	21.1	0.60	1.74	15.0	0.66	2.23	12.2	0.70	2.58	9.0	0.75	3.25	7.2	0.83	3.70	5.8	0.93	4.09	4.6	0.99	4.81			
20	39.0	0.57	1.33	28.1	0.61	1.74	19.9	0.66	2.26	16.2	0.70	2.62	12.0	0.75	3.26	9.5	0.81	3.84	7.6	0.89	4.35	6.1	0.97	4.95	5.3	1.06	5.21
25	48.6	0.57	1.34	35.1	0.61	1.73	24.8	0.66	2.28	20.3	0.70	2.59	15.0	0.75	3.27	11.9	0.81	3.82	9.5	0.89	4.37	7.6	0.96	5.03	6.5	1.02	5.56
30	58.1	0.57	1.34	42.0	0.61	1.74	29.7	0.66	2.28	24.3	0.70	2.61	18.0	0.76	3.26	14.2	0.80	3.89	11.3	0.87	4.49	9.1	0.96	5.08	7.8	1.01	5.59
35	67.6	0.57	1.35	48.8	0.61	1.75	34.6	0.66	2.28	28.2	0.70	2.64	20.9	0.75	3.30	16.6	0.81	3.86	13.2	0.88	4.47	10.5	0.94	5.26	9.1	1.01	5.60
40	77.0	0.57	1.35	55.7	0.61	1.75	39.5	0.66	2.28	32.2	0.70	2.64	23.9	0.75	3.29	18.9	0.80	3.90	15.1	0.88	4.46	12.0	0.94	5.26	10.3	0.99	5.77
45	86.4	0.57	1.35	62.5	0.61	1.75	44.3	0.66	2.29	36.1	0.70	2.65	26.8	0.75	3.31	21.3	0.81	3.87	16.9	0.87	4.52	13.5	0.94	5.25	11.6	1.00	5.75
50	95.7	0.57	1.36	69.2	0.61	1.76	49.1	0.66	2.30	40.1	0.70	2.64	29.7	0.75	3.32	23.6	0.81	3.89	18.8	0.88	4.50	15.0	0.94	5.25	12.9	1.00	5.73
55	105.0	0.57	1.36	75.9	0.61	1.77	53.9	0.66	2.30	44.0	0.70	2.65	32.6	0.75	3.33	25.9	0.81	3.90	20.6	0.87	4.54	16.5	0.94	5.24	14.1	0.99	5.84
60	114.2	0.57	1.36	82.6	0.61	1.77	58.7	0.66	2.30	47.9	0.70	2.66	35.5	0.75	3.34	28.2	0.81	3.92	22.4	0.87	4.57	17.9	0.93	5.32	15.4	0.99	5.81
65	123.4	0.57	1.36	89.3	0.61	1.77	63.4	0.66	2.31	51.8	0.70	2.66	38.4	0.75	3.34	30.5	0.81	3.92	24.3	0.87	4.54	19.4	0.94	5.30	16.7	1.00	5.78
70	132.4	0.57	1.37	95.9	0.61	1.77	68.2	0.66	2.31	55.6	0.70	2.67	41.3	0.75	3.34	32.8	0.81	3.93	26.1	0.87	4.56	20.8	0.93	5.36	17.9	0.99	5.85
75	141.5	0.57	1.37	102.4	0.61	1.78	72.9	0.66	2.31	59.4	0.70	2.68	44.1	0.75	3.36	35.1	0.81	3.93	27.9	0.87	4.58	22.3	0.93	5.34	19.2	1.00	5.82
80	150.5	0.57	1.37	109.0	0.61	1.78	77.5	0.66	2.32	63.3	0.70	2.68	47.0	0.75	3.36	37.4	0.81	3.92	29.7	0.87	4.60	23.8	0.94	5.32	20.4	0.99	5.88
90	168.8	0.57	1.38	122.3	0.61	1.79	87.0	0.66	2.33	71.0	0.70	2.69	52.8	0.75	3.36	42.0	0.81	3.93	33.4	0.87	4.59	26.7	0.94	5.35	22.9	0.99	5.91
100	187.0	0.57	1.38	135.5	0.61	1.79	96.5	0.66	2.33	78.7	0.70	2.70	58.5	0.75	3.37	46.5	0.81	3.96	37.0	0.87	4.62	29.6	0.93	5.38	25.5	0.99	5.86
110	205.1	0.57	1.38	148.7	0.61	1.79	105.9	0.66	2.33	86.4	0.70	2.70	64.3	0.75	3.37	51.1	0.81	3.96	40.7	0.87	4.61	32.5	0.93	5.39	28.0	0.99	5.88
120	223.1	0.57	1.39	161.8	0.61	1.80	115.3	0.66	2.33	94.1	0.70	2.70	70.0	0.75	3.38	55.7	0.81	3.96	44.3	0.87	4.62	35.4	0.93	5.41	30.5	0.99	5.89
130	240.9	0.57	1.39	174.8	0.61	1.80	124.6	0.66	2.34	101.7	0.70	2.71	75.7	0.76	3.38	60.2	0.81	3.97	47.9	0.87	4.64	38.3	0.93	5.41	33.0	0.99	5.90
140	258.7	0.57	1.40	187.7	0.61	1.81	133.9	0.66	2.34	109.3	0.70	2.71	81.3	0.75	3.39	64.7	0.81	3.98	51.5	0.87	4.64	41.2	0.93	5.42	35.5	0.99	5.91
150	276.4	0.58	1.40	200.6	0.61	1.81	143.1	0.66	2.35	116.8	0.70	2.72	87.0	0.76	3.39	69.3	0.81	3.97	55.1	0.87	4.65	44.1	0.93	5.42	37.9	0.99	5.96
160	293.9	0.58	1.40	213.4	0.61	1.81	152.3	0.66	2.35	124.3	0.70	2.72	92.6	0.76	3.40	73.7	0.81	3.99	58.7	0.87	4.65	47.0	0.94	5.42	40.4	0.99	5.95
170	311.4	0.58	1.40	226.1	0.61	1.82	161.5	0.66	2.35	131.8	0.70	2.73	98.2	0.76	3.41	78.2	0.81	3.99	62.3	0.87	4.65	49.9	0.94	5.41	42.9	0.99	5.95
180	328.7	0.58	1.41	238.8	0.61	1.82	170.6	0.66	2.36	139.2	0.70	2.73	103.8	0.76	3.41	82.7	0.81	3.99	65.9	0.87	4.65	52.7	0.93	5.44	45.4	0.99	5.94
190	346.0	0.58	1.41	251.4	0.61	1.83	179.7	0.67	2.36	146.6	0.70	2.74	109.4	0.76	3.41	87.1	0.81	4.00	69.4	0.87	4.67	55.6	0.94	5.43	47.8	0.99	5.97
200	363.1	0.58	1.42	263.9	0.61	1.83	188.7	0.67	2.37	154.0	0.70	2.74	114.9	0.76	3.42	91.6	0.81	4.00	73.0	0.87	4.66	58.4	0.94	5.45	50.3	0.99	5.96
220	398.3	0.58	1.42	289.6	0.62	1.83	207.1	0.67	2.37	169.0	0.70	2.75	126.1	0.76	3.43	100.6	0.81	4.00	80.1	0.87	4.68	64.2	0.94	5.45	55.2	0.99	5.99
240	433.2	0.58	1.42	315.0	0.62	1.84	225.4	0.67	2.37	184.0	0.70	2.75	137.4	0.76	3.43	109.5	0.81	4.01	87.3	0.87	4.68	69.9	0.94	5.46	60.2	0.99	5.98
260	467.9	0.58	1.43	340.4	0.62	1.84	243.7	0.67	2.38	198.9	0.70	2.76	148.5	0.76	3.44	118.5	0.81	4.01	94.4	0.87	4.69	75.6	0.94	5.47	65.1	0.99	5.99
280	502.5	0.58	1.43	365.6	0.62	1.84	261.8	0.67	2.38	213.7	0.70	2.76	159.7	0.76	3.44	127.4	0.81	4.02	101.5	0.87	4.70	81.4	0.94	5.46	70.0	0.99	6.01
300	536.7	0.58	1.43	390.7	0.62	1.85	279.9	0.67	2.38	228.5	0.71	2.77	170.7	0.76	3.45	136.2	0.81	4.03	108.6	0.87	4.70	87.0	0.94	5.48	74.9	0.99	6.01

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 11 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 6.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	34.6	0.53	1.22	22.6	0.57	1.72	16.6	0.61	2.20	12.6	0.65	2.68	10.0	0.70	3.15	8.1	0.76	3.59	6.6	0.82	4.05	5.3	0.90	4.61	4.3	0.98	5.19
20	46.0	0.53	1.22	30.0	0.57	1.73	22.1	0.61	2.20	16.8	0.66	2.68	13.2	0.69	3.25	10.7	0.74	3.71	8.7	0.80	4.22	7.0	0.88	4.79	5.7	0.96	5.36
25	57.2	0.52	1.23	37.4	0.57	1.74	27.6	0.61	2.20	21.0	0.66	2.68	16.5	0.69	3.25	13.3	0.73	3.78	10.8	0.79	4.32	8.7	0.86	4.90	7.0	0.92	5.69
30	68.5	0.53	1.23	44.7	0.57	1.75	33.0	0.61	2.22	25.1	0.66	2.70	19.8	0.69	3.24	16.0	0.74	3.75	13.0	0.80	4.29	10.4	0.86	4.97	8.4	0.92	5.71
35	79.6	0.53	1.24	52.0	0.57	1.76	38.4	0.61	2.22	29.2	0.65	2.71	23.0	0.69	3.28	18.6	0.74	3.78	15.1	0.79	4.34	12.1	0.85	5.01	9.8	0.92	5.72
40	90.6	0.52	1.24	59.3	0.57	1.76	43.8	0.61	2.22	33.3	0.65	2.72	26.3	0.69	3.26	21.2	0.74	3.80	17.2	0.79	4.37	13.8	0.85	5.04	11.2	0.92	5.72
45	101.6	0.53	1.25	66.5	0.57	1.76	49.1	0.61	2.24	37.4	0.66	2.72	29.5	0.69	3.28	23.8	0.73	3.81	19.4	0.79	4.33	15.5	0.85	5.05	12.5	0.91	5.85
50	112.5	0.53	1.25	73.6	0.57	1.77	54.4	0.61	2.24	41.5	0.66	2.72	32.7	0.69	3.29	26.4	0.74	3.82	21.5	0.79	4.35	17.2	0.85	5.06	13.9	0.91	5.83
55	123.3	0.53	1.25	80.8	0.57	1.77	59.7	0.61	2.25	45.5	0.66	2.73	35.9	0.69	3.29	29.0	0.74	3.82	23.6	0.79	4.37	18.8	0.84	5.15	15.3	0.92	5.82
60	134.1	0.53	1.26	87.8	0.57	1.78	65.0	0.61	2.25	49.5	0.66	2.74	39.1	0.69	3.30	31.6	0.74	3.82	25.7	0.79	4.38	20.5	0.84	5.14	16.6	0.91	5.90
65	144.7	0.53	1.26	94.9	0.57	1.78	70.2	0.61	2.26	53.5	0.66	2.75	42.2	0.69	3.32	34.1	0.73	3.85	27.8	0.79	4.38	22.2	0.85	5.14	18.0	0.91	5.87
70	155.3	0.53	1.27	101.9	0.57	1.79	75.4	0.61	2.26	57.5	0.66	2.75	45.4	0.69	3.31	36.7	0.74	3.84	29.9	0.79	4.39	23.9	0.85	5.13	19.3	0.91	5.94
75	165.8	0.53	1.27	108.8	0.57	1.80	80.6	0.61	2.26	61.5	0.66	2.75	48.5	0.69	3.33	39.2	0.73	3.86	31.9	0.79	4.43	25.5	0.84	5.18	20.7	0.91	5.91
80	176.3	0.53	1.27	115.7	0.57	1.80	85.8	0.61	2.27	65.4	0.66	2.76	51.7	0.69	3.32	41.8	0.74	3.85	34.0	0.79	4.42	27.2	0.85	5.16	22.0	0.91	5.96
90	197.6	0.53	1.28	129.8	0.57	1.80	96.2	0.61	2.28	73.4	0.66	2.77	58.0	0.69	3.33	46.9	0.74	3.87	38.2	0.79	4.43	30.5	0.84	5.20	24.8	0.91	5.91
100	218.8	0.53	1.28	143.8	0.57	1.81	106.6	0.61	2.28	81.4	0.66	2.77	64.3	0.69	3.34	52.0	0.74	3.88	42.4	0.79	4.42	33.9	0.85	5.18	27.5	0.91	5.93
110	239.9	0.53	1.28	157.7	0.57	1.81	117.0	0.61	2.28	89.3	0.66	2.78	70.6	0.69	3.35	57.1	0.74	3.88	46.5	0.79	4.45	37.2	0.84	5.20	30.2	0.91	5.95
120	260.8	0.53	1.29	171.5	0.57	1.82	127.3	0.61	2.29	97.2	0.66	2.79	76.9	0.69	3.35	62.2	0.74	3.89	50.7	0.79	4.44	40.5	0.84	5.22	32.9	0.91	5.96
130	281.5	0.53	1.29	185.3	0.57	1.82	137.6	0.61	2.29	105.1	0.66	2.79	83.1	0.69	3.36	67.2	0.74	3.90	54.8	0.79	4.46	43.8	0.84	5.23	35.6	0.91	5.96
140	302.1	0.53	1.30	199.0	0.57	1.83	147.8	0.61	2.30	112.9	0.66	2.80	89.3	0.69	3.36	72.3	0.74	3.90	58.9	0.79	4.46	47.1	0.84	5.24	38.3	0.91	5.97
150	322.6	0.53	1.30	212.6	0.57	1.83	157.9	0.61	2.30	120.7	0.66	2.80	95.5	0.69	3.37	77.3	0.74	3.91	63.0	0.79	4.47	50.4	0.84	5.24	40.9	0.91	6.01
160	342.9	0.53	1.30	226.1	0.57	1.84	168.0	0.61	2.31	128.5	0.66	2.80	101.7	0.69	3.37	82.3	0.74	3.91	67.1	0.79	4.47	53.7	0.85	5.24	43.6	0.91	6.00
170	363.1	0.53	1.31	239.6	0.57	1.84	178.0	0.61	2.32	136.2	0.66	2.81	107.8	0.69	3.37	87.3	0.74	3.91	71.2	0.79	4.47	56.9	0.84	5.27	46.3	0.91	5.99
180	383.1	0.53	1.31	253.0	0.57	1.84	188.0	0.61	2.32	143.9	0.66	2.81	113.9	0.69	3.38	92.2	0.74	3.93	75.2	0.79	4.49	60.2	0.85	5.26	48.9	0.91	6.02
190	403.0	0.53	1.32	266.3	0.57	1.85	197.9	0.61	2.33	151.5	0.66	2.82	120.0	0.70	3.38	97.1	0.74	3.94	79.3	0.79	4.49	63.4	0.84	5.28	51.6	0.91	6.01
200	422.7	0.53	1.32	279.5	0.57	1.85	207.8	0.61	2.33	159.1	0.66	2.82	126.1	0.70	3.39	102.1	0.74	3.93	83.3	0.79	4.50	66.7	0.85	5.27	54.2	0.91	6.03
220	463.4	0.53	1.32	306.6	0.57	1.86	228.0	0.61	2.33	174.6	0.66	2.83	138.4	0.70	3.39	112.0	0.74	3.95	91.5	0.79	4.50	73.2	0.85	5.29	59.6	0.91	6.02
240	503.8	0.53	1.33	333.6	0.57	1.86	248.1	0.61	2.34	190.1	0.66	2.83	150.7	0.70	3.40	122.0	0.74	3.95	99.7	0.80	4.50	79.8	0.85	5.28	64.9	0.91	6.04
260	543.8	0.53	1.33	360.4	0.57	1.86	268.1	0.61	2.34	205.4	0.66	2.84	162.9	0.70	3.40	131.9	0.74	3.96	107.8	0.80	4.51	86.3	0.85	5.29	70.2	0.91	6.05
280	583.6	0.53	1.34	387.0	0.57	1.87	287.9	0.61	2.35	220.7	0.66	2.85	175.1	0.70	3.41	141.8	0.74	3.96	115.9	0.80	4.51	92.8	0.85	5.30	75.5	0.91	6.05
300	623.2	0.53	1.34	413.5	0.58	1.87	307.7	0.61	2.36	235.9	0.66	2.85	187.2	0.70	3.41	151.6	0.74	3.97	123.9	0.80	4.53	99.3	0.85	5.30	80.8	0.91	6.06

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 12 of 14)

V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 8.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	37.0	0.47	1.26	26.6	0.51	1.65	18.7	0.54	2.19	15.3	0.57	2.54	11.7	0.61	3.08	9.4	0.65	3.61	7.9	0.70	3.99	6.4	0.74	4.62	5.3	0.80	5.18
20	49.2	0.47	1.26	35.3	0.50	1.66	24.9	0.54	2.19	20.4	0.57	2.54	15.6	0.61	3.08	12.5	0.65	3.65	10.4	0.68	4.17	8.5	0.74	4.70	7.1	0.80	5.16
25	61.2	0.47	1.27	44.0	0.50	1.67	31.0	0.54	2.21	25.4	0.57	2.56	19.4	0.61	3.12	15.6	0.65	3.67	13.0	0.68	4.17	10.6	0.73	4.75	8.8	0.79	5.32
30	73.2	0.47	1.28	52.6	0.50	1.67	37.2	0.54	2.19	30.4	0.57	2.57	23.3	0.61	3.10	18.7	0.65	3.67	15.6	0.68	4.17	12.7	0.73	4.77	10.5	0.78	5.41
35	85.1	0.47	1.28	61.2	0.50	1.68	43.2	0.54	2.21	35.3	0.57	2.59	27.1	0.61	3.12	21.7	0.64	3.72	18.1	0.68	4.23	14.8	0.73	4.78	12.2	0.77	5.48
40	96.9	0.47	1.28	69.7	0.50	1.68	49.3	0.54	2.21	40.3	0.57	2.59	30.9	0.61	3.13	24.8	0.64	3.71	20.7	0.68	4.20	16.9	0.73	4.78	13.9	0.77	5.53
45	108.6	0.47	1.29	78.2	0.51	1.68	55.3	0.54	2.22	45.2	0.57	2.60	34.6	0.61	3.16	27.8	0.64	3.73	23.2	0.68	4.24	19.0	0.73	4.78	15.7	0.78	5.45
50	120.2	0.48	1.29	86.5	0.50	1.69	61.2	0.54	2.23	50.0	0.57	2.62	38.4	0.61	3.15	30.9	0.65	3.71	25.8	0.68	4.21	21.0	0.73	4.84	17.4	0.78	5.48
55	131.8	0.48	1.30	94.9	0.51	1.70	67.1	0.54	2.24	54.9	0.57	2.62	42.1	0.61	3.17	33.9	0.65	3.73	28.3	0.68	4.23	23.1	0.73	4.83	19.1	0.78	5.50
60	143.2	0.48	1.30	103.1	0.51	1.70	73.0	0.54	2.24	59.7	0.57	2.62	45.9	0.61	3.16	36.9	0.65	3.73	30.8	0.68	4.24	25.1	0.73	4.87	20.8	0.78	5.51
65	154.6	0.48	1.30	111.4	0.51	1.71	78.9	0.54	2.24	64.5	0.57	2.63	49.6	0.61	3.16	39.9	0.65	3.74	33.3	0.68	4.25	27.2	0.73	4.85	22.5	0.78	5.52
70	165.9	0.48	1.31	119.5	0.51	1.71	84.7	0.54	2.25	69.3	0.57	2.63	53.2	0.61	3.19	42.8	0.64	3.76	35.8	0.68	4.26	29.2	0.73	4.88	24.1	0.77	5.59
75	177.1	0.48	1.31	127.6	0.51	1.72	90.5	0.54	2.25	74.1	0.57	2.63	56.9	0.61	3.19	45.8	0.65	3.76	38.2	0.68	4.29	31.2	0.73	4.90	25.8	0.77	5.59
80	188.2	0.48	1.32	135.6	0.51	1.72	96.2	0.54	2.26	78.8	0.57	2.64	60.5	0.61	3.20	48.7	0.64	3.78	40.7	0.68	4.29	33.3	0.73	4.87	27.5	0.77	5.58
90	210.9	0.48	1.32	152.1	0.51	1.73	108.0	0.55	2.26	88.4	0.57	2.65	67.9	0.61	3.21	54.7	0.65	3.78	45.7	0.68	4.29	37.4	0.73	4.88	30.9	0.77	5.59
100	233.5	0.48	1.32	168.4	0.51	1.73	119.6	0.55	2.27	98.0	0.57	2.65	75.3	0.61	3.21	60.7	0.65	3.78	50.6	0.68	4.32	41.4	0.73	4.92	34.2	0.77	5.64
110	255.9	0.48	1.33	184.6	0.51	1.74	131.2	0.55	2.28	107.5	0.57	2.66	82.6	0.61	3.22	66.6	0.65	3.79	55.6	0.68	4.32	45.5	0.73	4.91	37.6	0.77	5.63
120	278.1	0.48	1.33	200.7	0.51	1.74	142.7	0.55	2.28	116.9	0.57	2.67	89.9	0.61	3.22	72.5	0.65	3.79	60.5	0.68	4.33	49.5	0.73	4.93	40.9	0.77	5.66
130	300.2	0.48	1.34	216.6	0.51	1.75	154.1	0.55	2.29	126.4	0.57	2.67	97.1	0.61	3.24	78.3	0.65	3.81	65.4	0.68	4.34	53.6	0.73	4.92	44.3	0.77	5.64
140	322.1	0.48	1.34	232.5	0.51	1.76	165.5	0.55	2.29	135.7	0.57	2.67	104.4	0.62	3.23	84.2	0.65	3.81	70.3	0.68	4.34	57.6	0.73	4.93	47.6	0.77	5.66
150	343.9	0.48	1.34	248.3	0.51	1.76	176.8	0.55	2.30	145.0	0.57	2.68	111.5	0.61	3.25	90.0	0.65	3.82	75.2	0.68	4.35	61.6	0.73	4.94	50.9	0.77	5.67
160	365.5	0.48	1.35	264.0	0.51	1.76	188.1	0.55	2.30	154.3	0.57	2.68	118.7	0.62	3.25	95.8	0.65	3.82	80.0	0.68	4.36	65.6	0.73	4.94	54.2	0.77	5.68
170	386.9	0.48	1.35	279.6	0.51	1.77	199.3	0.55	2.31	163.5	0.57	2.69	125.8	0.62	3.26	101.6	0.65	3.82	84.8	0.68	4.37	69.5	0.73	4.97	57.5	0.77	5.69
180	408.2	0.48	1.36	295.1	0.51	1.77	210.4	0.55	2.31	172.7	0.57	2.69	132.8	0.62	3.27	107.3	0.65	3.84	89.7	0.68	4.36	73.5	0.73	4.96	60.8	0.77	5.69
190	429.3	0.48	1.36	310.5	0.51	1.78	221.4	0.55	2.32	181.8	0.57	2.70	139.9	0.62	3.27	113.0	0.65	3.84	94.4	0.68	4.38	77.4	0.73	4.98	64.0	0.77	5.71
200	450.2	0.48	1.36	325.7	0.51	1.78	232.4	0.55	2.32	190.8	0.57	2.71	146.9	0.62	3.28	118.7	0.65	3.85	99.2	0.68	4.39	81.4	0.73	4.97	67.3	0.77	5.71
220	493.4	0.48	1.37	357.1	0.51	1.79	254.9	0.55	2.33	209.4	0.58	2.71	161.1	0.62	3.29	130.3	0.65	3.85	108.9	0.68	4.39	89.3	0.73	4.99	73.9	0.77	5.72
240	536.2	0.48	1.37	388.3	0.51	1.79	277.3	0.55	2.34	227.8	0.58	2.71	175.4	0.62	3.29	141.8	0.65	3.86	118.6	0.68	4.40	97.3	0.74	4.99	80.5	0.77	5.72
260	578.8	0.48	1.38	419.3	0.51	1.80	299.5	0.55	2.34	246.2	0.58	2.72	189.5	0.62	3.30	153.3	0.65	3.87	128.2	0.68	4.40	105.2	0.74	5.00	87.0	0.77	5.74
280	621.1	0.48	1.38	450.1	0.51	1.80	321.6	0.55	2.35	264.4	0.58	2.72	203.6	0.62	3.31	164.8	0.65	3.87	137.8	0.68	4.41	113.1	0.74	5.00	93.5	0.77	5.76
300	663.1	0.48	1.39	480.7	0.51	1.81	343.6	0.55	2.35	282.6	0.58	2.73	217.6	0.62	3.31	176.1	0.65	3.88	147.4	0.69	4.41	120.9	0.74	5.02	100.1	0.78	5.75

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 13 of 14)

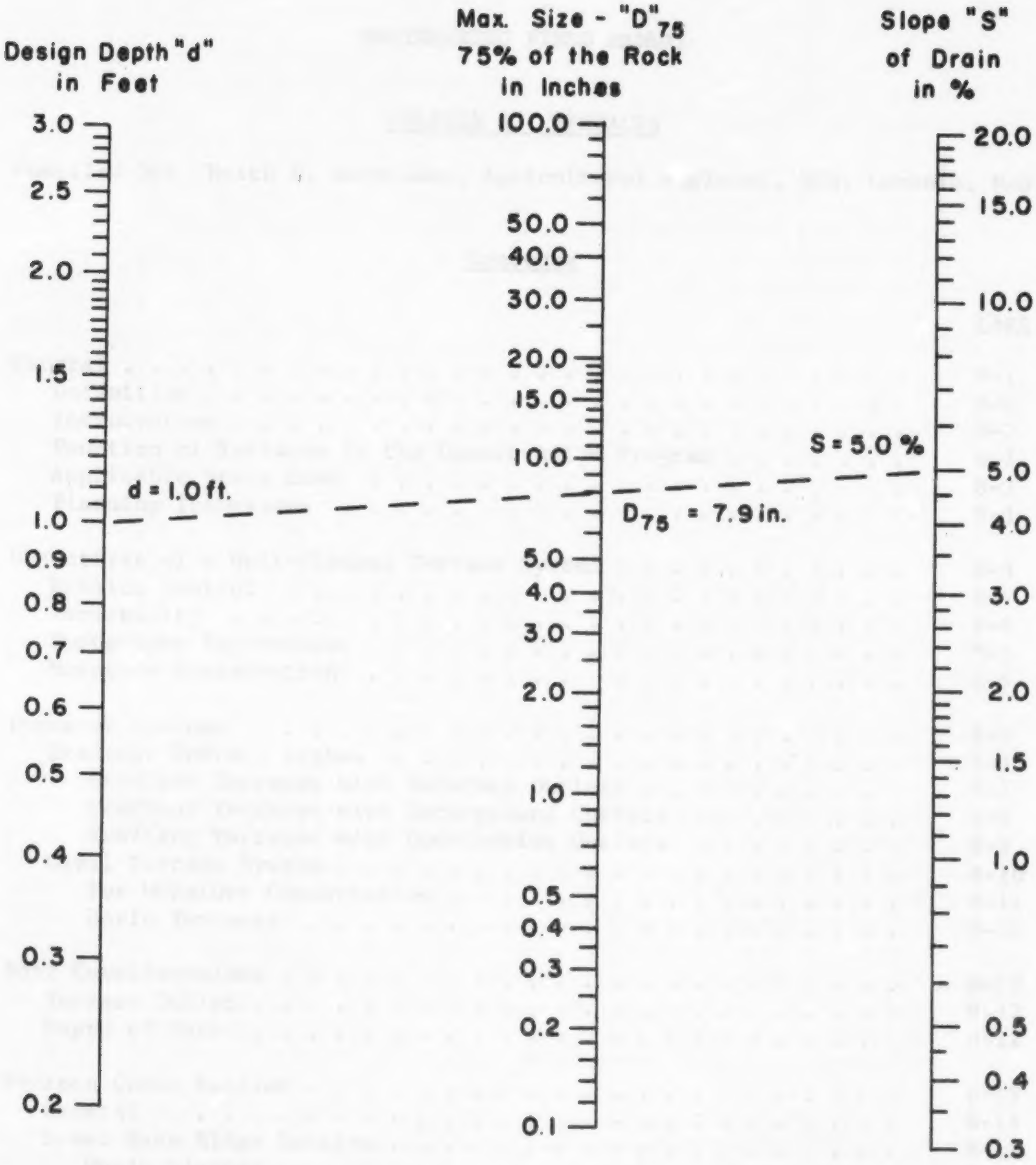
V_1 for **RETARDANCE "D"**. Top Width (T), Depth (D) and V_2 for **RETARDANCE "C"**.

Grade 10.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	45.2	0.43	1.14	32.5	0.45	1.50	22.9	0.49	1.98	16.6	0.52	2.56	13.4	0.55	2.99	10.7	0.58	3.55	9.0	0.61	3.99	7.4	0.65	4.57	6.2	0.70	5.08
20	60.1	0.43	1.14	43.2	0.45	1.50	30.4	0.49	2.00	22.1	0.52	2.56	17.8	0.55	3.02	14.3	0.59	3.52	12.0	0.61	4.00	9.9	0.65	4.55	8.3	0.70	5.06
25	74.8	0.43	1.15	53.8	0.45	1.51	37.9	0.49	2.00	27.5	0.52	2.59	22.3	0.55	2.99	17.8	0.58	3.56	14.9	0.61	4.08	12.3	0.65	4.63	10.3	0.69	5.18
30	89.3	0.43	1.15	64.2	0.45	1.52	45.3	0.49	2.01	33.0	0.52	2.58	26.6	0.55	3.03	21.3	0.58	3.58	17.9	0.61	4.05	14.7	0.64	4.68	12.4	0.70	5.13
35	103.7	0.43	1.16	74.6	0.45	1.53	52.6	0.48	2.03	38.3	0.52	2.60	31.0	0.55	3.02	24.8	0.58	3.59	20.8	0.61	4.09	17.2	0.65	4.63	14.4	0.69	5.19
40	118.0	0.43	1.16	85.0	0.46	1.53	59.9	0.48	2.04	43.7	0.52	2.60	35.3	0.55	3.04	28.3	0.58	3.59	23.6	0.61	4.06	19.6	0.65	4.66	16.4	0.69	5.24
45	132.2	0.43	1.17	95.2	0.45	1.53	67.2	0.49	2.04	49.0	0.52	2.61	39.6	0.55	3.05	31.7	0.58	3.62	26.7	0.61	4.08	22.0	0.65	4.68	18.4	0.69	5.27
50	146.3	0.43	1.17	105.3	0.45	1.54	74.4	0.49	2.04	54.3	0.52	2.61	43.9	0.55	3.05	35.2	0.58	3.61	29.6	0.61	4.09	24.4	0.65	4.68	20.4	0.69	5.28
55	160.2	0.43	1.17	115.4	0.46	1.55	81.5	0.49	2.06	59.5	0.52	2.63	48.2	0.55	3.05	38.6	0.58	3.62	32.4	0.61	4.13	26.7	0.64	4.74	22.4	0.69	5.29
60	174.0	0.43	1.18	125.3	0.46	1.55	88.6	0.49	2.06	64.7	0.52	2.63	52.4	0.55	3.07	42.0	0.58	3.63	35.3	0.61	4.12	29.1	0.65	4.73	24.4	0.69	5.30
65	187.6	0.43	1.18	135.2	0.46	1.56	95.6	0.49	2.07	69.9	0.52	2.64	56.6	0.55	3.08	45.4	0.58	3.64	38.2	0.61	4.12	31.5	0.65	4.72	26.4	0.69	5.30
70	201.2	0.43	1.19	145.0	0.46	1.57	102.6	0.49	2.08	75.1	0.52	2.64	60.8	0.55	3.08	48.7	0.58	3.66	41.0	0.61	4.14	33.8	0.65	4.75	28.4	0.69	5.29
75	214.6	0.43	1.19	154.7	0.46	1.57	109.6	0.49	2.08	80.2	0.52	2.65	65.0	0.55	3.08	52.1	0.58	3.66	43.8	0.61	4.15	36.2	0.65	4.74	30.3	0.69	5.34
80	227.9	0.43	1.20	164.3	0.46	1.58	116.4	0.49	2.09	85.3	0.52	2.65	69.1	0.55	3.09	55.4	0.58	3.67	46.6	0.61	4.16	38.5	0.65	4.76	32.3	0.69	5.33
90	255.2	0.43	1.20	184.1	0.46	1.58	130.5	0.49	2.10	95.6	0.52	2.67	77.5	0.55	3.11	62.1	0.58	3.69	52.3	0.61	4.17	43.2	0.65	4.78	36.3	0.69	5.33
100	282.4	0.43	1.20	203.7	0.46	1.59	144.5	0.49	2.10	105.9	0.52	2.67	85.9	0.56	3.11	68.8	0.58	3.70	58.0	0.61	4.18	47.9	0.65	4.78	40.2	0.69	5.36
110	309.2	0.43	1.21	223.2	0.46	1.60	158.4	0.49	2.11	116.2	0.52	2.68	94.3	0.56	3.11	75.5	0.58	3.71	63.7	0.61	4.18	52.6	0.65	4.79	44.2	0.69	5.34
120	335.9	0.43	1.21	242.4	0.46	1.60	172.2	0.49	2.12	126.4	0.52	2.68	102.5	0.56	3.12	82.2	0.58	3.71	69.3	0.61	4.19	57.3	0.65	4.79	48.1	0.69	5.36
130	362.3	0.43	1.22	261.6	0.46	1.61	185.9	0.49	2.12	136.5	0.52	2.69	110.8	0.56	3.13	88.8	0.58	3.72	74.9	0.61	4.20	61.9	0.65	4.81	52.0	0.69	5.37
140	388.4	0.44	1.22	280.5	0.46	1.61	199.5	0.49	2.13	146.5	0.52	2.70	119.0	0.56	3.13	95.4	0.58	3.73	80.5	0.61	4.20	66.5	0.65	4.82	55.9	0.69	5.38
150	414.4	0.44	1.23	299.3	0.46	1.62	213.0	0.49	2.13	156.5	0.52	2.71	127.1	0.56	3.14	101.9	0.58	3.74	86.0	0.61	4.22	71.1	0.65	4.83	59.7	0.69	5.41
160	440.1	0.44	1.23	318.1	0.46	1.62	226.5	0.49	2.14	166.4	0.53	2.71	135.2	0.56	3.15	108.4	0.58	3.75	91.6	0.62	4.21	75.7	0.65	4.83	63.6	0.69	5.41
170	465.5	0.44	1.24	336.7	0.46	1.63	239.8	0.49	2.14	176.3	0.53	2.72	143.3	0.56	3.15	114.9	0.58	3.76	97.1	0.62	4.22	80.3	0.65	4.83	67.4	0.69	5.42
180	490.8	0.44	1.24	355.1	0.46	1.63	253.1	0.49	2.15	186.1	0.53	2.73	151.3	0.56	3.16	121.3	0.58	3.77	102.5	0.62	4.24	84.9	0.65	4.83	71.3	0.69	5.42
190	515.7	0.44	1.25	373.5	0.46	1.64	266.3	0.49	2.15	195.9	0.53	2.73	159.3	0.56	3.17	127.7	0.58	3.78	108.0	0.62	4.24	89.4	0.65	4.84	75.1	0.69	5.43
200	540.5	0.44	1.25	391.6	0.46	1.64	279.4	0.49	2.16	205.6	0.53	2.74	167.2	0.56	3.17	134.1	0.58	3.79	113.4	0.62	4.25	93.9	0.65	4.85	78.9	0.69	5.43
220	592.0	0.44	1.26	429.2	0.46	1.65	306.3	0.49	2.17	225.4	0.53	2.75	183.5	0.56	3.18	147.1	0.58	3.80	124.4	0.62	4.26	103.1	0.65	4.85	86.6	0.69	5.45
240	643.0	0.44	1.26	466.4	0.46	1.65	333.1	0.49	2.17	245.2	0.53	2.75	199.6	0.56	3.19	160.0	0.58	3.81	135.4	0.62	4.27	112.2	0.65	4.87	94.3	0.69	5.45
260	693.6	0.44	1.27	503.4	0.46	1.66	359.6	0.49	2.18	264.8	0.53	2.76	215.6	0.56	3.19	172.9	0.58	3.82	146.4	0.62	4.27	121.3	0.65	4.87	101.9	0.69	5.47
280	743.7	0.44	1.27	540.0	0.46	1.66	386.0	0.49	2.18	284.4	0.53	2.77	231.6	0.56	3.20	185.8	0.59	3.82	157.3	0.62	4.28	130.4	0.65	4.88	109.6	0.69	5.47
300	793.4	0.44	1.28	576.4	0.46	1.67	412.3	0.49	2.19	303.8	0.53	2.77	247.5	0.56	3.21	198.6	0.59	3.83	168.1	0.62	4.29	139.4	0.65	4.89	117.2	0.69	5.48

Exhibit 7-5 Parabolic waterway design
(Retardance "D" and "C")

(Sheet 14 of 14)



EXAMPLE: "d" = 1.0 Feet "S" = 5 %

Place straight edge at "d" value in Design Depth column and at "S" value in Slope column. Read rock size in middle column 7.9 inches. Say 8 inches.

FOR DESIGN:

25 % of the rock by volume should be in sizes of 8 inches or slightly larger. The remaining 75 % or less should be of well graded material, smaller than 8 inches, including sufficient sands and gravels to fill the voids between the larger rock.

Exhibit 7-6 Determination of rock size for stone center waterway

ENGINEERING FIELD MANUAL

CHAPTER 8. TERRACES

Compiled by: Keith H. Beauchamp, Agricultural Engineer, SCS, Lincoln, Neb.

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ENGINEERING FIELD MANUAL

CHAPTER 8. TERRACES

1. GENERAL

DEFINITION

A terrace is an earth embankment, or a ridge and channel, constructed across the slope at a suitable location to intercept surface runoff water. It may be constructed with an acceptable grade to an outlet or with a level channel and ridge.

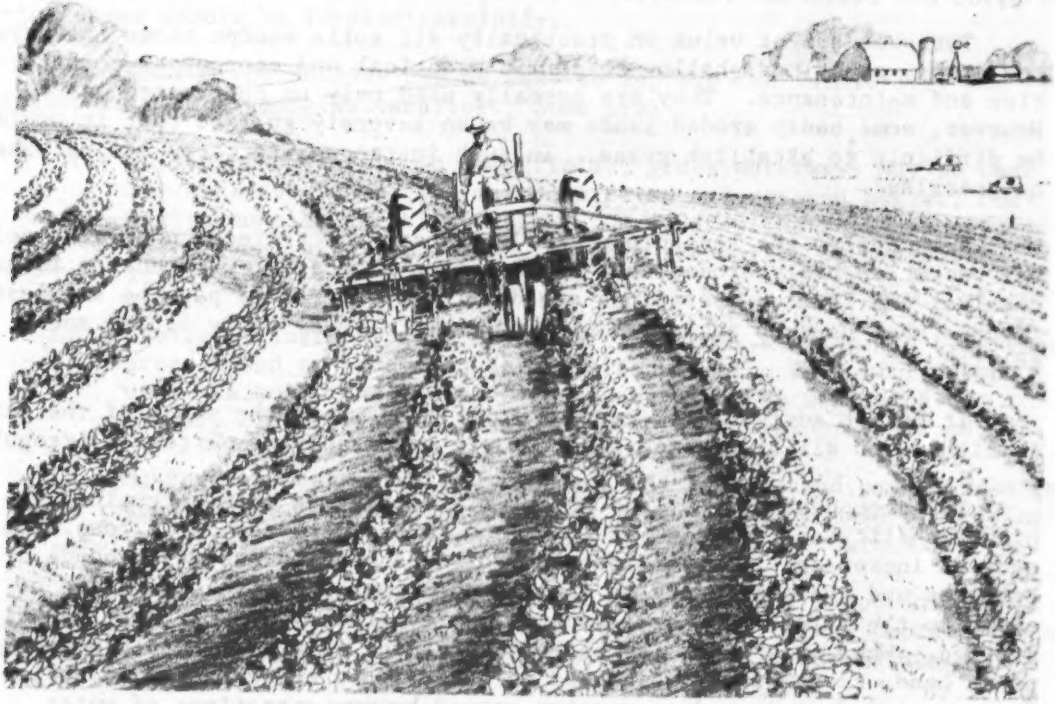


Figure 8-1 An erosion control terrace planted to row crops

INTRODUCTION

Terraces are constructed to reduce erosion by shortening the length of slope and conducting the runoff water on a nonerosive grade to a stable outlet. They are used also to conserve moisture; reduce floods by means of level closed terraces, or by increasing the time of concentration with graded terraces; and to control gully heads downstream.

Terracing is one of the best mechanical erosion control practices. To be accepted by farmers, terraces must have desirable shape and alignment and be farmable with modern equipment.

FUNCTION OF TERRACES IN THE CONSERVATION PROGRAM

Terraces that are properly located, constructed and maintained reduce runoff and soil losses and prevent the forming of rills and gullies. They assist in reclaiming badly gullied fields by intercepting the runoff before it becomes concentrated and attains an eroding velocity. Terraces prevent the loss of costly seed and plant foods. To be effective, they must be used in combination with other practices, such as stubble mulching, contouring, and stripcropping. Over a period of years, better crops may be expected on terraced land because of the soil and moisture they save.

Terraces are of value on practically all soils except those that are too stony, sandy, or shallow to permit practical and economical construction and maintenance. They are normally used only on cultivated lands. However, some badly eroded lands may be so severely gullied that it would be difficult to establish grass. In such instances, terraces are necessary on grassland.

Frequently, the less productive soils are not terraced until the soil has become so badly eroded that construction is costly, maintenance is excessive, and farming operations are difficult. Terraces pay the smallest returns when used to reclaim fields that are already badly eroded and gullied.

It is not advisable to terrace some lands where the slope of the land is either too slight or excessive, or the topography is extremely irregular.

The steepness of the land is one of the factors that determines the practicability of terraces. As the land slope increases, soil loss from erosion increases. However, the cost of construction and maintenance of terraces and the difficulty of farming them increase with the degree of slope to the point that these factors may eventually outweigh the benefits derived. When this point is reached, terracing is not advisable. On the other hand, terraces may be needed on long slopes as gentle as one-half foot per 100 feet to reduce erosion caused by concentrations of water.

The steepest slope on which terracing is practical is not determined by formula but by the economics, industry of the operator, and the accompanying conservation practices applied. Terraces are being employed successfully on slopes as steep as 12 percent on residual and glacial soils and on slopes up to 20 percent on loess soils, when proper land use is practiced.

It is difficult to lay out a farmable terrace system on very irregular slopes. Curves that are too sharp for modern farm machinery cannot be avoided, except by excessive cuts and fills. Most soils in this type of topography are too shallow to permit deep cuts. Hence, spacing between terraces will vary and cause many point rows.

APPLICABLE STATE LAWS

Applicable state laws governing the diversion of water must be followed in planning and installing terrace systems. Generally, state laws require that water must not be diverted so that it leaves a farm at a point other than the natural watercourse.

PLANNING TECHNIQUES

A major requirement of a good terrace system for row crops is that the terraces must have the best possible alignment and be parallel wherever possible. With parallel terraces, each terrace is planned as part of a total system. A parallel terrace system can have correction areas provided they occur between sets of parallel terraces. However, the correction areas should be located carefully.

A number of techniques can be used to improve the farmability and to assist in making terraces parallel. Some are:

1. Choice of outlets. On some fields, grass waterways may be best for outlets. Some jobs may require an underground outlet, commonly knows as the tile outlet. On others, the terraces may be built level with closed ends so that the outlet is the soil itself.
2. Choice of terrace cross section. The cross section may be either broad based or have a steep grass backslope. This will depend upon the soil, the slope of the field, and the wishes of the farmer. The terrace channel may be either flat or V-shaped.
3. Making terraces parallel. The cut-and-fill method may be used on some fields. On others, parallel layouts may be made by varying the grade, using grass turn strips, and other techniques.

All of these techniques should be considered in the layout of any terrace system. A well-planned system requires throughtful, detailed planning which will result in a system that is easy to farm and maintain.

2. OBJECTIVES OF A WELL-PLANNED TERRACE SYSTEM

There are several general objectives to be kept in mind in terrace planning. These are erosion control, farmability, topography improvement, and moisture conservation where level terraces are used.

EROSION CONTROL

Erosion control is the prime objective in terracing. The technician should consider the allowable soil loss, the most intensive use expected for the land, and the expected level of management in planning terraces for erosion control. This means that terraces must generally fit the contour of the land. Deviations from the selected grade must be limited, and allowed only when necessary to obtain good alignment.

FARMABILITY

Farmability is a second important objective. Terraces must be as farmable as possible in order to have them accepted and maintained. A terrace system with good farmability will:

1. Have the best possible alignment and be parallel wherever possible for row crops. This will reduce point rows, save time in plowing, planting and harvesting, and reduce crop damage caused by turning between terraces. When only grain or hay crops are grown, parallel terraces are not so important provided the terrace cross section is flat enough to permit easy crossing with farm machinery.

2. Be spaced to fit the equipment used in the area. If farmers are using 4-row equipment, terracing spacing should be adapted to multiples of four rows. If the trend is 6- and 8-row equipment (or other special types) terrace spacing should be planned, if possible, to fit present and future equipment.

3. Be spaced as wide as possible without exceeding the allowable soil loss.

4. Be planned and constructed with a workable cross section. The cross section should not increase the slope of the land to the point where it is difficult to farm. Some terracing increases the slope of the land between the terraces because earth is taken from the channel and placed in the ridge. An increase in slope can be tolerated on the flatter land but any increase in slope on steep land tends to make farming operations slower, decrease stands, and reduce efficiency. One solution on the steep land is to develop a steep terrace back slope and seed it to permanent vegetation. Another is to borrow fill material below the terrace to make the ridge, and seed the steep back slope. These methods will flatten the land between terraces and should be used where applicable.

5. Provide good access roads to all parts of the terraced field. This is very important for erosion control. Roads can be provided on field ridges, along the side of grass waterways, and along field boundaries. Waterways should never be used for roads.

TOPOGRAPHY IMPROVEMENT

In planning a terrace system to improve the topography of a field, the terraces are laid out fairly straight and smooth, taking them directly across minor draws and gullies. After the terraces are built there will be some soil movement in the terrace interval, caused both by equipment and by water. However, any soil that moves will be deposited in low areas, thus smoothing the field and making it more farmable.

Another method of improving the topography of a field is to do some benching or promote benching between terraces. Benching between terraces will occur to some extent on steep slopes with wide spacing, intensive cropping and improper plowing. On deep soils of fairly uniform texture, such as the deep loess soils, benching between parallel terraces will provide a flatter slope to farm, better moisture distribution over the benched area, and reduce downhill sliding of equipment. By constructing terraces mainly from the downhill side the slope between terraces will be reduced. Then there are two ways to speed up the benching process:

1. Use earthmoving equipment to construct the bench at the time the terraces are installed. On steep slopes this is very costly.

2. Speed up the natural process by plowing to move the soil downhill. The spacing must be set so that the terrace ridge can be raised as needed.

Often, it is desirable to do some land grading of the entire field, or between terraces after they have been built. This is necessary if old conventional terraces still remain in the field. Also, there may be depressed areas that will continue to slow the movement of water into terrace channels unless graded out. Land grading should be considered as one means of topography improvement.

MOISTURE CONSERVATION

In areas of low rainfall, and particularly in the semiarid regions where the soil is highly permeable, level terraces with closed ends are used for moisture conservation as well as erosion control. Surface runoff is stored back of the terrace ridge and is slowly absorbed by the soil.

3. TYPES OF SYSTEMS

There are two major types of terrace systems based on the disposal of runoff. One is the gradient terrace system and the other the level terrace system. The system to be used will be determined by the characteristics of the soil to be terraced and the rainfall.

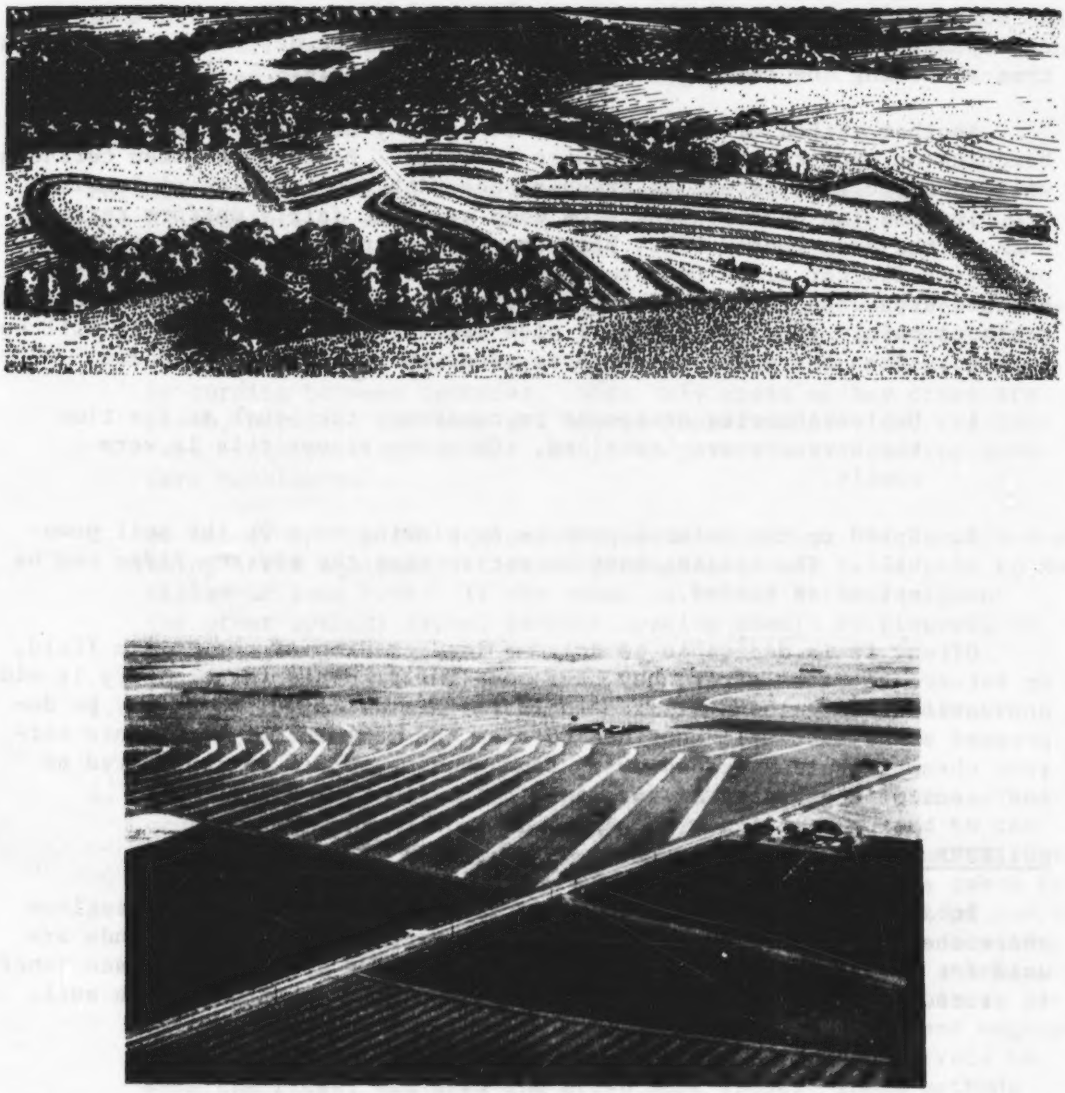


Figure 8-2 Well planned terrace systems

GRADIENT TERRACE SYSTEM

Gradient terraces carry the collected runoff in a graded channel to an outlet. Outlets are of two types, surface or subsurface. Surface outlets are waterways either natural or constructed. Subsurface outlets are underground conduits, such as tile or pipe.

Gradient Terraces With Waterway Outlets

The gradient terrace which uses a grass waterway for an outlet is the most common type. Erosion is controlled because the slope length of the field is reduced to that of the terrace spacing. When runoff occurs, the flow travels overland to the terrace and thence along the terrace at a safe velocity to the waterway outlet. See Figure 8-3.

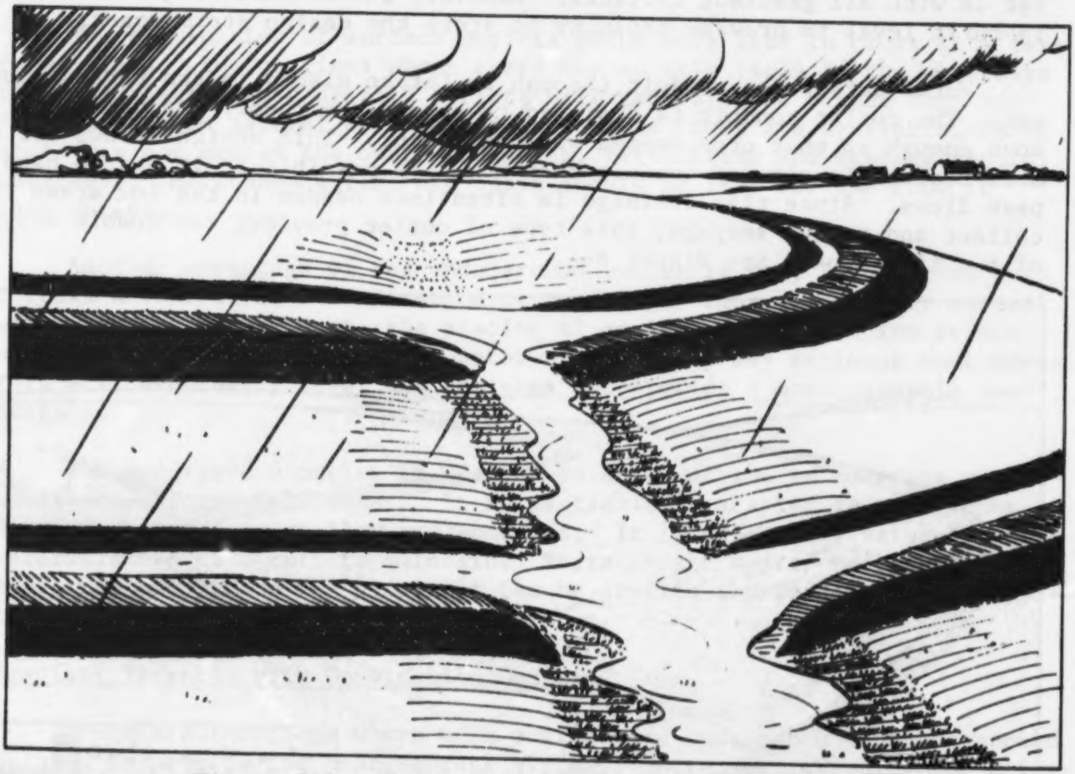


Figure 8-3 Gradient terraces with waterway outlet

Channel grades may be either uniform or variable. Grades should be sufficient to provide good drainage and develop adequate flow without scouring the channel and washing out crops.

This type of terrace system requires an outlet of suitable capacity that can be maintained in good vegetative cover. Gullies developing in an outlet could extend up the terrace channels, causing failure of the entire system. The location of the outlet will depend primarily upon topographical features, types of outlets to be used, and the effect of the location on the convenience of carrying out farming operations. Refer to Chapter 7 for additional information and design criteria for vegetated outlets.

Grade control structures in vegetative outlets will be needed where flow velocities are greater than the sod can handle; at gully heads that are impractical to blade out; and at junctions with another outlet where it is necessary to raise the end of the waterway above unfavorable conditions for sod growth because of poor soil, rocky, or wet conditions. See Chapter 6 for information on structure selection.

Gradient Terraces With Underground Outlets

With this type of terrace system the outlet is a conduit made of tile, pipe or other suitable material. The terrace channel is graded to the outlet as with all gradient terraces. However, the terrace ridgetop usually is built level to provide capacity to store the design storm runoff.

Water enters the conduit through an intake placed in the terrace channel. The outlet conduit is designed to remove the runoff gradually but soon enough so that crop damage will not occur. This design allows for a more reasonable size of conduit than would be possible if it had to handle peak flows. Since tile drainage is oftentimes needed in the low areas to collect and remove seepage, this type of outlet provides for double usage of the tile line. See Figure 8-4.

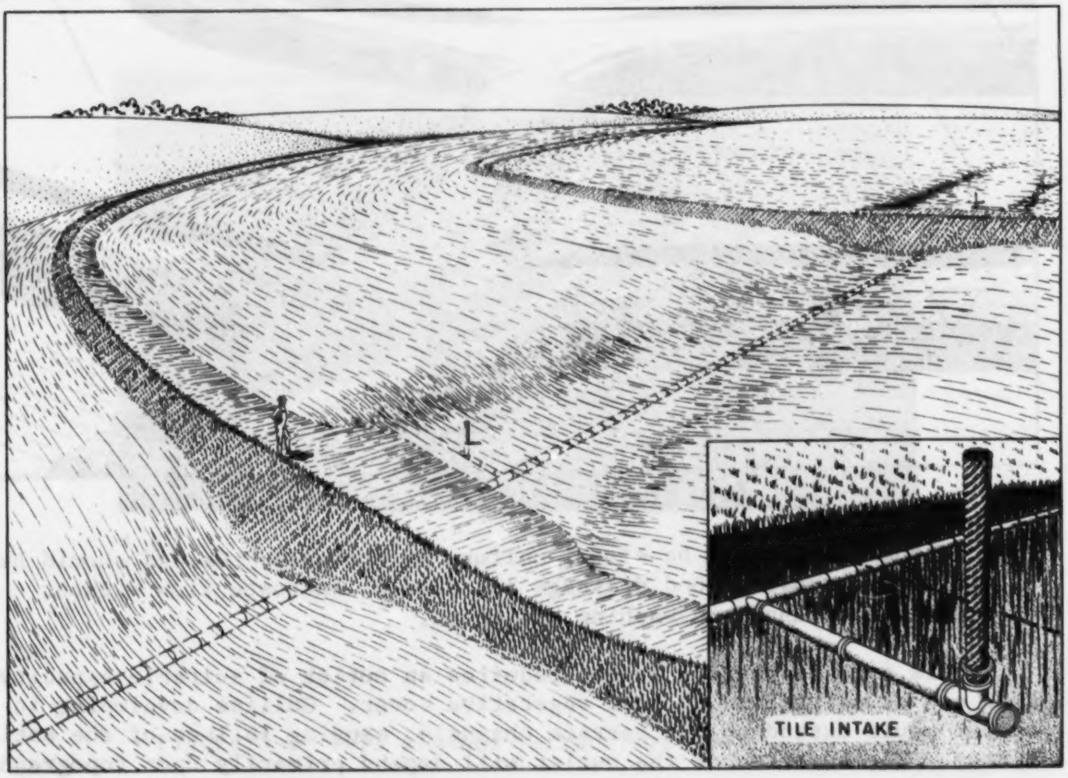


Figure 8-4 Gradient terraces with tile outlets

The two main advantages of the underground outlet are that it promotes parallel alignment and eliminates the need for grass waterways. The use of this type of outlet requires the terraces to be built across the depressions and waterways with the intake being placed at the low point on the terrace profile. With shallow depressions the terrace can be built straight across, thus giving a straighter line than if a surface outlet were used. Straighter lines are easier to parallel.

With the underground outlet, steeper grades can be permitted in the terrace channel near the outlet. This is because the larger rains will cause water to be stored at the outlet, which will reduce the grade of the water surface and thereby reduce the velocity. The velocity of flow from small rains will not be a problem. By being able to steepen grades at the larger depressions or waterways where outlets will be established, straighter alignment is possible.

The elimination of surface outlets means more land in crops in a terraced field. In locations where there are no tile lines in the waterways the installation cost of tile outlets will generally be higher than surface outlets in natural waterways. Where tile lines are available, inlet costs may not exceed the cost of shaping, fertilizing and seeding natural waterways. Maintenance time and costs should be less for the conduit type outlet.

Another advantage of the underground outlet is that it provides a certain amount of land restoration or topography improvement. If natural waterways are rather deep, the placing of an intake at these low points with a fill straight across the waterway will trap any sediment that moves. This will eventually level out the area and provide a more farmable land surface.

The underground outlet is adapted to soils of low to moderate permeability in all rainfall areas. It is particularly adapted to topography where waterways are shallow and numerous. It is especially valuable where waterways are difficult to maintain. Terraces are easier to parallel on rough topography and the alignment can be greatly improved in terrace systems not planned to be parallel.

Gradient Terraces With Combination Outlets

There are locations where both surface and underground outlets should be used to provide the best terrace system. Where straightening the alignment and developing a good sod are not a problem, the vegetative outlet might work better for a part of the system. In another part of the same system, with rougher topography and deeper draws, the tile outlet might be more suitable.

Where there is a good vegetated waterway that does not require tile it should be used to serve as much as possible of the system. Where only a portion, or one end, of a terrace requires an outlet, the possibility of a surface outlet should be explored. Another portion of the field might have numerous waterways or draws that could be eliminated with underground outlets.

Where good vegetation is difficult to establish or maintain and sufficient storage for an underground outlet is impractical to construct, a standard broad base terrace can be constructed across the waterway at either the first or second terrace from the top. The terrace slopes should be seeded to permanent vegetation and an underground outlet provided for low flows and snowmelt that cause undue erosion in a vegetated waterway.

The technician should carefully study the topography of the field and the location of required outlets and use the type of outlet best adapted for each location.

LEVEL TERRACE SYSTEM

A level terrace is constructed with no channel grade. The channel and ridgetop are built level so that runoff is stored along the terrace. The ends of the terrace usually are closed; therefore, the soil absorbs the water and serves as the terrace outlet. See Figure 8-5. Sometimes the ends of the terrace are left open or partially open. In these cases adequate outlets must be available. The outlet may be a grass waterway, vegetated area, or tile outlet.

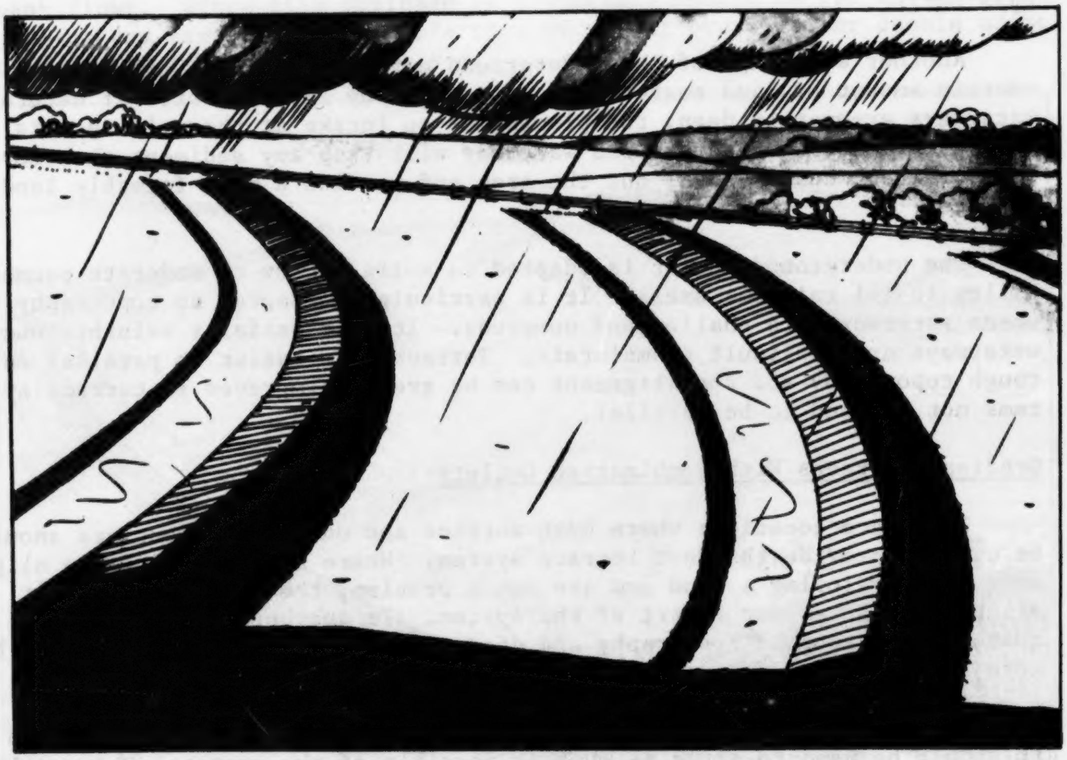


Figure 8-5 Level terraces

The level terrace with complete or partial end closures can be used only on highly permeable soils capable of absorbing the runoff rapidly enough to prevent damage to terraces and crops. On less permeable soils no end closures are used. This type of terrace is adapted to areas of low to moderate rainfall, generally not to exceed a 25- to 30-inch annual rainfall depending upon soil depth and texture.

The level terrace is used both for erosion control and water conservation. It is generally used in areas of suitable soils where outlets are a problem and runoff from the area must be kept to a minimum or entirely eliminated. It is particularly adapted to areas of low rainfall for conserving moisture.

The soils on which level terraces are needed for erosion control usually are highly productive but quite erodible. The land is often carved with shallow gullies. Level terracing will control and smooth out the land in these situations, in addition to conserving moisture.

Storage requirements of level terraces necessitate a fairly large cross section. The terraces must be large enough to contain the design storm runoff without overtopping the terrace ridge. Overtopping may start a chain reaction from terrace to terrace with increasing damage. The runoff volume of a 10-year frequency storm is used to determine the required storage capacity for closed level terraces.

For Moisture Conservation

Level terraces are used for moisture conservation and erosion control in areas of low rainfall. The terraces collect and store surface runoff so that it can be absorbed into the soil. All surface runoff is thereby converted to soil moisture.

In some areas a special type of level terrace called flat-channel terrace or conservation bench is used for moisture control. This terrace is constructed with a ridge and a wide, flat channel as shown in Figure 8-6. The terrace ridge controls the impounding and spreading of runoff water. The level bench or channel serves as a catchment area for surface runoff from the terrace interval.

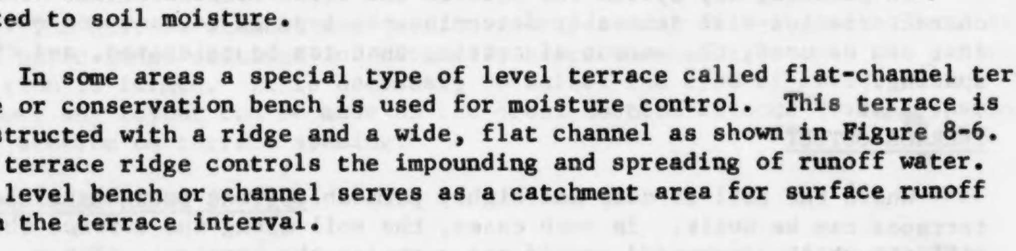


Figure 8-6 Cross section of flat channel moisture conservation terraces

The terrace ends are closed or partially closed to retain the water on the flat channel. The flat channel section is designed to fit the equipment used. The channel width depends also on the slope of the land and should be designed so that channel cut will balance with ridge fill. Width also depends upon land use and anticipated runoff. Usually this type of terrace is adapted to slopes up to 4 percent with channel widths varying from 30 to 70 feet. Terrace spacing may be the same as for regular terraces plus the width of the flat channel section. The channel provides an area of uniform width and level land for farming row crops. The contributing area is generally used for small grain.

Basin Terraces

The basin terrace is a form of level terrace with closed ends constructed on noncropped deep permeable soils and designed to impound a given amount of runoff from its drainage area above. Usually it is constructed at the base of steep noncultivated land that is not terraceable. The terrace will retain the runoff from the noncropland area, thereby checking erosion on the lower slopes, preventing gully development, reducing flooding and increasing infiltration opportunity.

The basin terrace should have a storage capacity, without overtopping, adequate to handle the expected runoff volume of a 10-year frequency storm. A nonfarmable cross section is generally used with terrace side slopes steeper and narrower than cropland terraces. The channel can be parabolic, V-shaped or trapezoidal.

4. SOIL CONSIDERATIONS

In planning any system the soil is the first consideration. The soil characteristics will generally determine the type of terrace and outlet that can be used, the amount of cutting that can be tolerated, and the spacing.

TERRACE OUTLET

Where the soil is deep and highly permeable (like deep loess) level terraces can be built. In such cases, the soil along the terrace channel will absorb the impounded runoff and serve as the terrace outlet.

If the soil is not deep and permeable, the terrace should be graded to an outlet. Therefore, the soil dictates the type of outlet required and hence the type of terrace system.

DEPTH OF CUTS

Adequate investigation should be made to determine the depth of topsoil. Larger cuts can be made on deep soils to improve alignment without exposing unfavorable subsoil. Economics may be the determining factor, however, cuts must be kept to a minimum, which limits the flexibility of the layout.

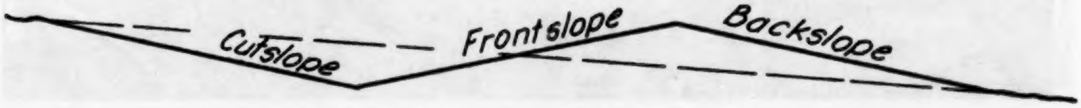
The exposing of small amounts of unfavorable subsoil is permissible in order to obtain satisfactory alignment of a parallel terrace system. When evaluating the soils, the improvement of the entire field should be weighed against exposing small infertile areas.

Consideration should be given to the time and cost of restoring exposed subsoil to good productivity. Some subsoils respond more quickly to treatment than others. One other approach on shallow soils is to stockpile topsoil before construction, remove the borrow, and replace the topsoil. This is a more costly method but it permits better alignment without seriously depressing yields.

5. TERRACE CROSS SECTION

GENERAL

The terrace cross section, consisting of channel and ridge must be proportioned to fit the land slope, the crops grown and farm machinery used. It is made up of three side slopes known as the cut slope, front slope and back slope as shown in Figure 8-7. The steeper limits for side slopes are generally accepted as 5:1 for row crops and 4:1 for drill crops.



Terrace Cross Section Showing the Three Slopes

Figure 8-7 Terrace cross section showing the three slopes

The terrace channel may be either trapezoidal or V-shaped. There are two basic ridge sections for terraces, based on whether or not the entire section is farmed. It is necessary to select the type of cross section before any layout can be made as the cross section affects terrace spacing. See section on terrace spacing.

BROAD BASE RIDGE SECTION

The broad base terrace is constructed so that modern farm machinery can operate over the cut slope, front slope, and back slope without difficulty. The front slope is made a width which fits the common machinery in the area. The cut slope and the back slope are made at least as wide as the front slope. Borrow is usually taken from the uphill side. (See Figure 8-8.)

Where Adapted

The broad base ridge section is generally adapted to the land slopes less than 8 percent. On steeper slopes it will be difficult to make the back slope farmable. It is better adapted to smooth topography rather than rough.

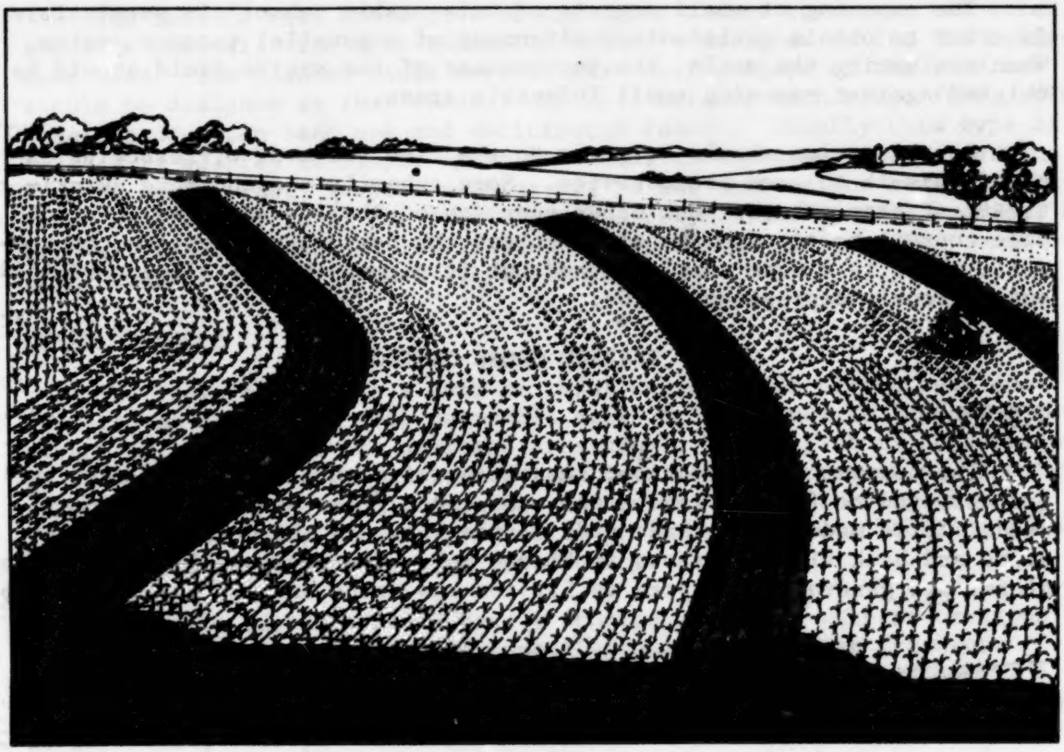


Figure 8-8 Broad base ridge section

Advantages

The entire terrace can be farmed with no land lost to crops. There is no problem of weeds, trees, and burrowing animals.

Limitations

This ridge section requires a large amount of earthfill because all back slopes are relatively long. This is especially true where large fills are necessary. On steep land it is difficult to keep the back slope from getting too steep, thereby presenting a safety hazard. It should not be used on land with slopes over 10 percent. This type of section tends to increase the land slope appreciably between terraces on the steeper land.

GRASS BACK SLOPE RIDGE SECTION

The grass back slope ridge section is constructed with a steep back slope, generally 2:1. Since the back slope is too steep for row crops, it must be maintained in sod. The front slope is made to fit the farm equipment. The cut slope, where borrow is taken on the uphill side, generally is made at least as wide as the front slope so that it, too, is farmable. See Figure 8-9.

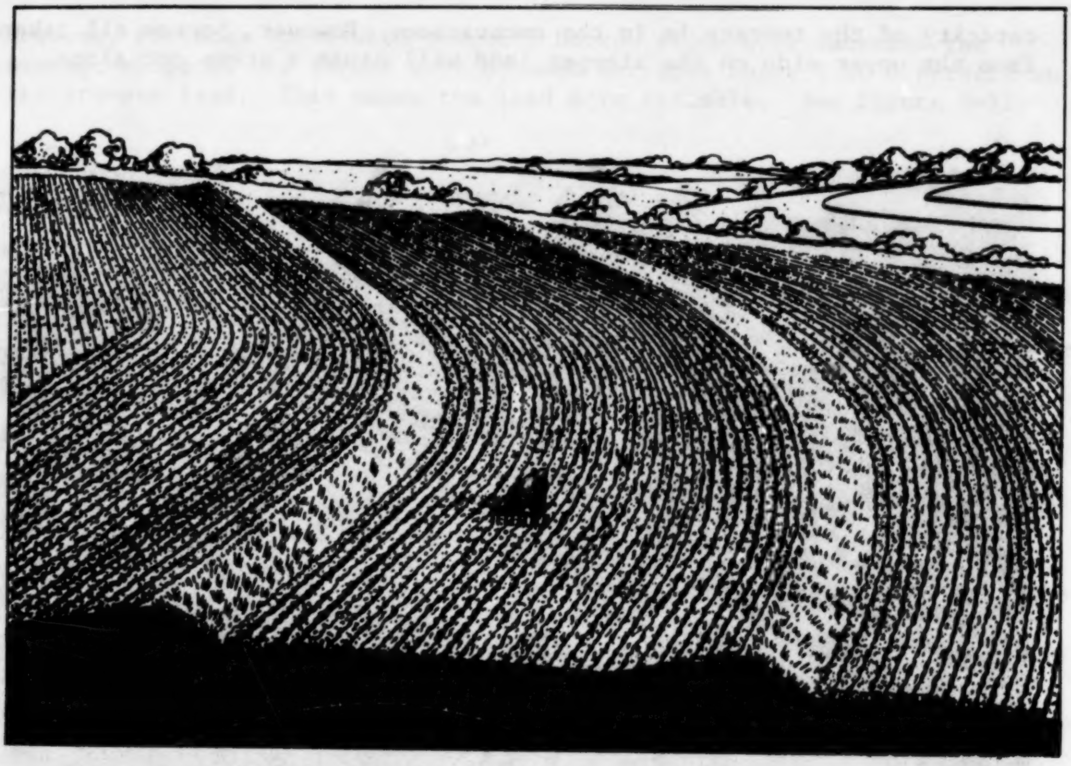


Figure 8-9 Grass back slope ridge section

Where Adapted

The grass back slope ridge section is better adapted to slopes of 6 per cent or greater.

Advantages

The grass back slope ridge section, particularly when borrow is taken from the downhill side, makes the land more farmable. Also, the slope of the land between terraces is reduced. Less earth is required in the heavier fills. The safety hazard associated with farming steep back slopes is removed. Note good grass back slope in Figure 8-10.

Limitations

The back slope must be maintained in sod. Trees, weeds, and burrowing animals must be controlled. A small portion of the land is removed from cropland and each terrace interval is a separate field.

Borrow

Borrow can be taken all from the uphill side, all from the downhill side, or from both sides. When borrow is taken only from the upper side, less earthfill is required in the terrace ridge because part of the capacity of the terrace is in the excavation. However, borrow all taken from the upper side on the steeper land will cause a steep cut slope.

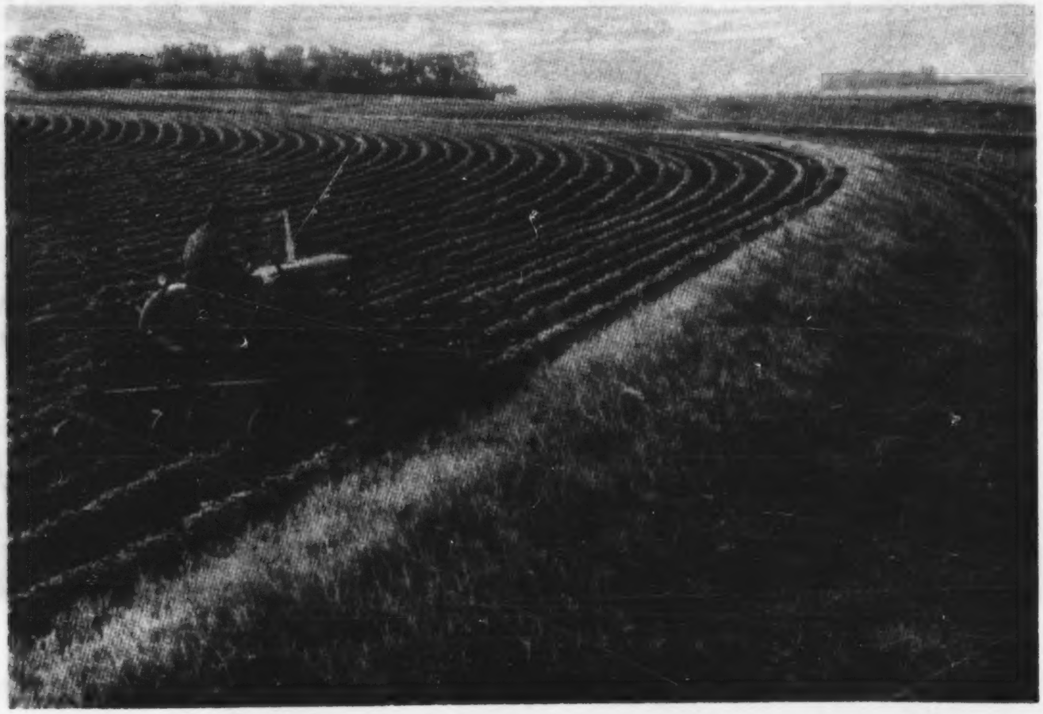
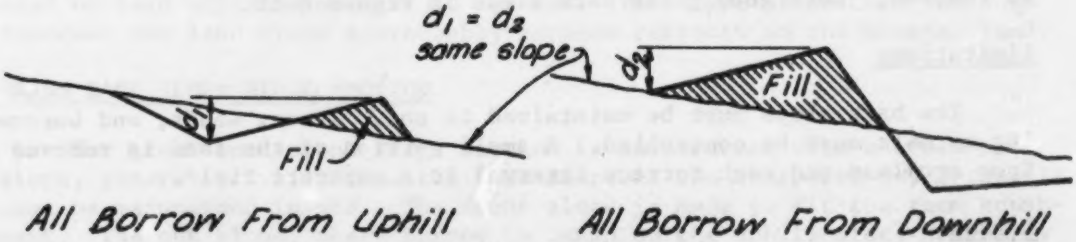


Figure 8-10 Example of a well maintained grass back slope

Where borrow is taken only from the downhill side, the depth of earthfill placed in the terrace ridge must be greater because capacity occurs only above the natural ground, with no excavated capacity. (Figure 8-11)



All Borrow From Uphill   All Borrow From Downhill

Figure 8-11 Comparing uphill and downhill borrow

However, terraces built with downhill borrow alone will decrease the average slope of the farmed area between terraces about 2 to 4 percent on the steeper land. This makes the land more farmable. See Figure 8-12.

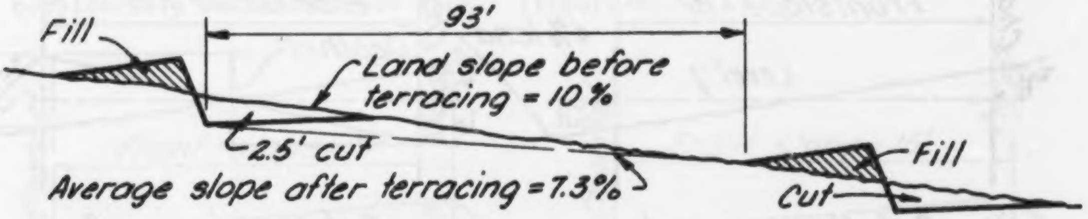

Fill
93'
Land slope before terracing = 10%
2.5' cut
Average slope after terracing = 7.3%
Fill
Cut

Figure 8-12 Average slope decreased

Borrow can be made from both sides, particularly on slopes steeper than 12 percent. This reduces terrace height and yardage as compared to terraces built entirely from the lower side. The back slope is still left steep and is seeded.

When cuts and fills are made along the terrace line, borrow should be taken from the ridges and moved to the depressions. This will reduce the slope in the channel and the slope of those rows close to the terrace. It also tends to level out the land and make the width of the back slope more uniform which makes the system more farmable.

All Borrow from Upper Side

The effect of borrow from the upper side, and the effect of land slope on the cross section of the terrace should be considered. In the usual case, the cut slope and back slope are made equal in length and excavation approximately equals the earthfill. This assumes no shrink or swell of the borrow, which is generally true. The result is two triangles, with the area of the borrow triangle equal to the area of the earthfill triangle. Therefore, the depth of cut equals the depth of fill.

Figure 8-13 shows an assumed case of a terrace built on a level area. If the terrace is to be 1.0 foot in total height, it will be necessary to excavate 0.5 foot, fill a like amount, and the resulting height (from bottom of excavation to top of fill) will be 1.0 foot.

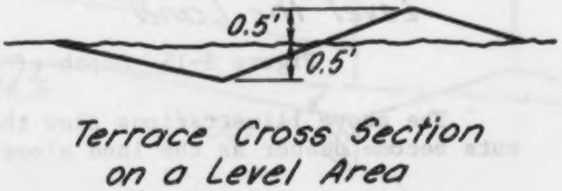
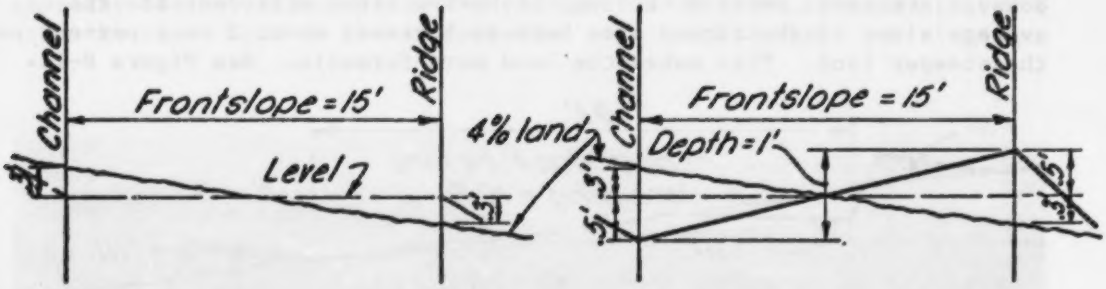


Figure 8-13 Terrace cross section on a level area

A more realistic case is a terrace on a 4 percent slope. Again determine the depth of cut necessary for the 1.0-foot terrace. First determine the depth necessary to level the land. If the terrace front slope is 15 feet in length the land slopes 15 (.04) = 0.6 foot in this length. Thus, it will be necessary to cut 0.3 foot and fill 0.3 foot to level the area. Now to make the terrace one foot high, it will be necessary to cut an additional 0.5 foot. Thus, the total cut will be 0.3 foot plus 0.5 foot or 0.8 foot. (Figure 8-14)

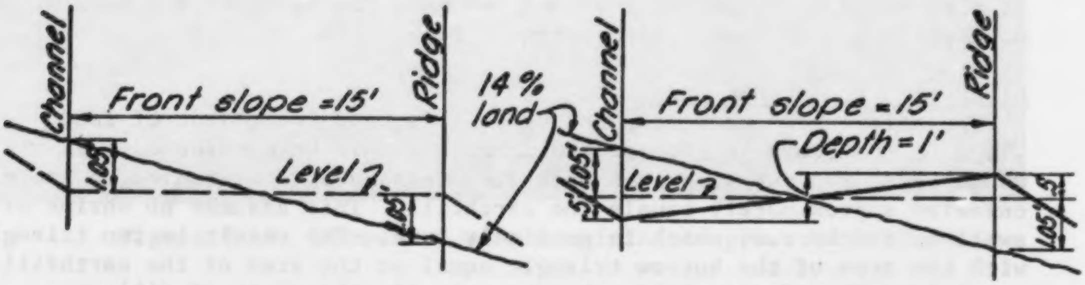

Channel
Frontslope = 15'
Ridge
Level
.3'
.3'
4% land
Channel
Frontslope = 15'
Ridge
Depth = 1'
.5'
.3'
.5'
.5'
.3'

Cut Necessary to Level the Land

Cut Necessary for 1' High Terrace

Figure 8-14 Depth of cut on 4 percent slope

Now consider a similar terrace on a 14 percent slope. The land slopes 2.1 feet in the 15 feet from the channel to the ridge. A cut of 1.05 feet will be necessary to first level the area. Add to this an additional 0.5 foot as before, and it is found that a total cut of 1.55 feet is necessary for the same 1.0-foot high terrace. (Figure 8-15)


Channel
Front slope = 15'
Ridge
1.05'
Level
1.05'
14 % land
Channel
Front slope = 15'
Ridge
Depth = 1'
.5'
1.05'
Level
.5'
1.05'

Cut Necessary to Level the Land

Cuts Necessary for 1' High Terrace

Figure 8-15 Depth of cut on 14 percent slope

The above illustrations show that with the broad base cross section cuts become deeper as the land slope becomes steeper.

Consideration also should be given to the effect on land slope when terraces are built with borrow from the upper side. Take as an example a 14 percent slope. As was shown above, a cut of 1.55 feet and a fill of 1.55 feet were necessary for a 1.0-foot terrace. If the terraces are 80 feet apart, the new average slope will be increased by 4.8 percent to 18.8 percent.

$$\frac{(65)(.14) + 1.55 + 1.55}{65} = 0.188 \text{ or } 18.8 \text{ percent}$$

This is based on measuring the new slope from the top of the terrace ridge to the bottom of the channel of the next lower terrace, a distance of 65 feet. Thus, it can be seen that broad base terraces increase the slope considerably on the steeper land. (Figure 8-16)

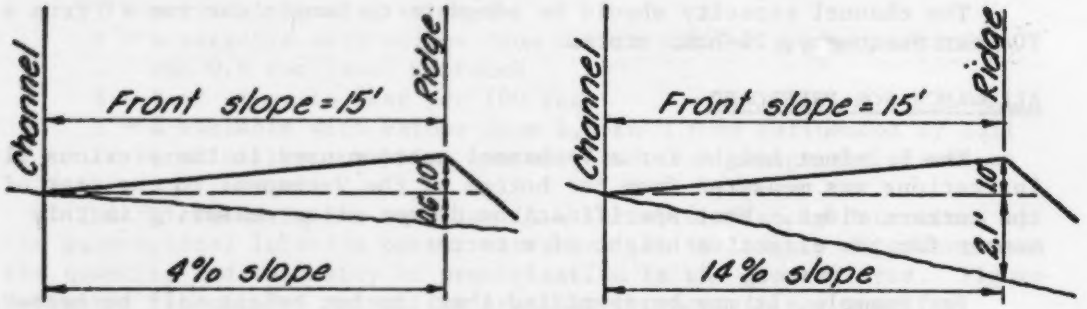


Figure 8-16 Slope increased with broad base ridge section

All Borrow from Lower Side

Consider the fill height at the terrace if there is no excavation on the uphill side. For the 4 percent slope, the fill height needed to level the base is 0.6 foot. An additional 1.0 foot is necessary to give the one foot fill height, making 1.6 feet total fill. This is twice as high a fill as when borrow was made on the uphill side. This same relationship is true for all slopes. (Figure 8-17)

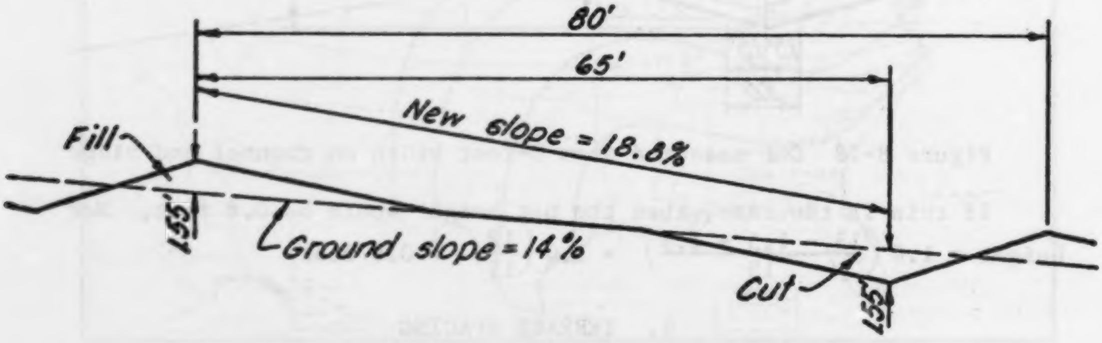


Figure 8-17 No excavation on uphill side

CHANNEL

The trapezoidal channel is more adapted to the flatter land slopes where sufficient fill for the ridge can be obtained from shallow depths of cut. Narrow channels are satisfactory only for small machinery. The flat channel terrace previously discussed has a wide, flat trapezoidal channel designed to accommodate the equipment that is to be used on them. This type channel is adapted to slopes up to around 4 percent.

The V-shaped channel can be used on any terraceable slope. It is more economical to construct than the trapezoidal channel on the steeper slopes. The broad, shallow V-channel is better adapted to larger machinery like 6- and 8-row equipment.

The channel capacity should be adequate to handle the runoff from a 10-year frequency, 24-hour storm.

ALLOWANCE FOR FREEBOARD

The 1.0-foot height for a V-channel section used in the previous illustrations was measured from the bottom of the V-channel to the peak of the terrace ridge. Most specifications do not allow measuring in this manner for the effective height of a terrace.

For example, it may be specified that the net height will be measured from the 3-foot width on both the channel and the ridge as shown in Figure 8-18.

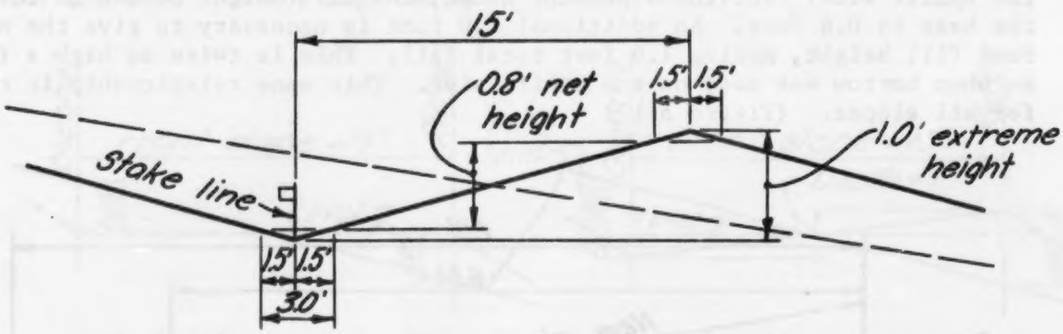


Figure 8-18 Cut measured from 3-foot width on channel and ridge

If this is the case, then the net height would be 0.8 foot. Net height $= 1.0\left(\frac{15 - 1.5 - 1.5}{15}\right) = 1.0\left(\frac{12}{15}\right) = 0.8$ foot

6. TERRACE SPACING

Terrace spacing depends mainly upon land slope. However, it also depends upon the soil and climate. The cross section will have some effect on the horizontal spacing. The crops to be grown and the machinery that will be used should also be considered.

Terrace spacings for various slopes, soils, and management conditions are prescribed in the Work Unit Technical Guide.

Terrace spacing is determined by either of two methods. One is by using the equation VI = XS + Y. The other is by applying the Universal Equation for predicting soil loss.

TERRACE SPACING EQUATION

The equation VI = XS + Y gives the maximum vertical spacing. In this equation:

VI = vertical spacing in feet
X = a variable with values from 0.4 to 0.8 for graded terraces, and 0.8 for level terraces
S = land slope in feet per 100 feet
Y = a variable with values from 1.0 to 4.0 as influenced by soil erodibility, cropping systems, and crop management practices

The "X" value in the equation is a variable which is determined by the geographical location of the terraces. It is largely dependent upon the quantity and intensity of precipitation in the general area. Figure 8-9 gives recommended values for gradient terraces in any specific location.

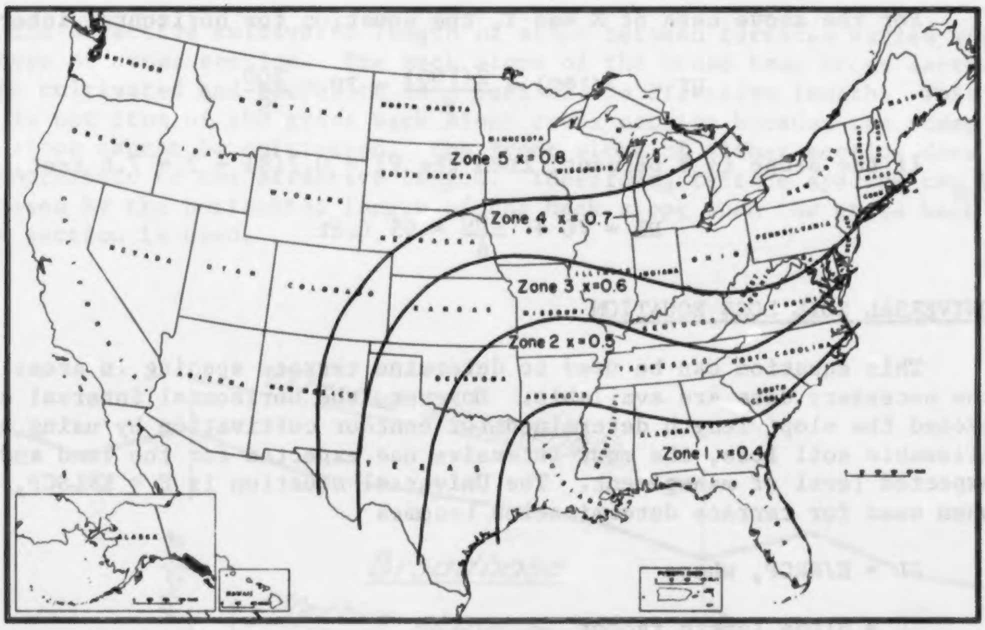


Figure 8-19 Values of X in Equation VI = XS + Y

The values of Y generally used are as follows:

Y = 1.0 for soils with below average intake rates and cropping systems that provide little cover during intense rainfall periods
Y = 4.0 for soils with average or above intake rates and cropping systems that provide good cover during periods of intense rainfall
Y = 2.5 where one of the above factors is favorable and the other unfavorable

Terrace spacings usually have been determined vertically using a vertical interval formula with the predominant slope between terraces. The terraces were then spaced a vertical distance apart. Usually there was no attempt made to determine horizontal interval.

With parallel terraces the horizontal interval is important in order to fit equipment and trips through the field. The vertical interval is used only as a means to determine horizontal interval. The vertical interval equation VI = XS + Y can be arranged to determine the horizontal interval.

For example, if the value of X is 0.7 and Y is 2, then the equation becomes VI = 0.7S + 2.

The equation can be arranged to determine horizontal interval.

$$HI = X(100) + \frac{Y(100)}{S}$$

For the above case of X and Y, the equation for horizontal interval

$$HI = .7(100) + \frac{2(100)}{S} = 70 + \frac{200}{S}$$

If the slope is 8 percent, then the VI = 0.7(8) + 2 = 7.6 feet, and the

$$HI = 70 + \frac{200}{8} = 95 \text{ feet}$$

UNIVERSAL SOIL LOSS EQUATION

This equation can be used to determine terrace spacing in areas where the necessary data are available. However, the horizontal interval cannot exceed the slope length determined for contour cultivation by using the allowable soil loss, the most intensive use expected for the land and the expected level of management. The Universal equation is E = KRLSCP, which, when used for terrace determination becomes

SL = E/KRCP, where

L = Slope length factor
S = Land slope factor
E = Allowable soil loss in tons per acre per year
K = Soil factor
R = Rainfall erosion factor
C = Cropping management factor
P = Mechanical practice factor

Example: Determine terrace spacing for a 7 percent slope for E = 5.0, K = .32, R = 190, C = .24 and P = .45.

Then SL = 5 + (.32 x 190 x .24 x .45) = .76.

The equation to calculate the horizontal interval (HI) when SL has been determined is:

$$SL = \frac{\sqrt{HI}}{100}\left(0.76 + 0.53S_1 + 0.076S_1^2\right) \text{ or}$$

$$HI = \left[\frac{100\ SL}{0.76 + 0.53S_1 + 0.076S_1^2}\right]^2$$

where "S_1" is land slope in percent - in this case ($S_1 = 7$)

$$HI = \left[\frac{100 \times 0.76}{0.76 + 0.53 \times 7 + 0.076 \times 7^2}\right]^2 = 86.5 \text{ feet}$$

The above factors, if available, may be found in the SCS Work Unit Technical Guide.

SPACING AFFECTED BY CROSS SECTION

The effective cultivated length of slope between terraces varies with the type of cross section. The back slope of the broad base cross section can be cultivated and therefore is a part of the effective length. This then is not true of the grass back slope cross section because the steep back slope cannot be cultivated. The front slope of either section does not contribute to the effective length. Therefore, terrace spacing can be increased by the horizontal length of the back slope when the grass back slope section is used.

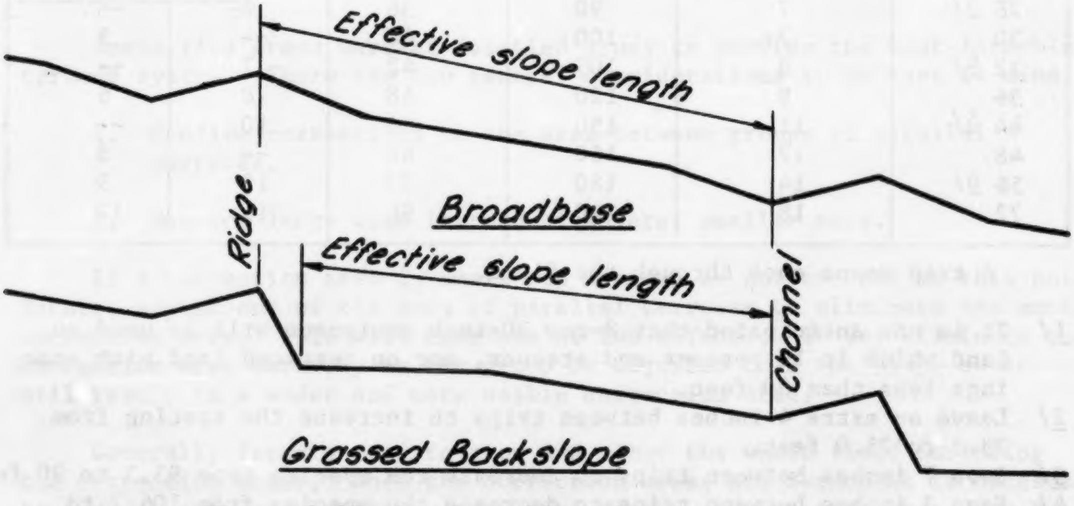


Figure 8-20 Spacing affected by cross section

SPACING ADJUSTED FOR MACHINERY

If the terraces are parallel but are not spaced to fit the equipment used on them, they are not as farmable as they could be. If the common equipment is 4-row with 40-inch row spacing, then terraces should be planned on multiples of 13 ft. 4 inches. They will be more farmable yet if planned on round trips of the equipment, in this case, multiples of 8 rows, or 26 ft. or 8 inches. The front slope should have a width that will fit the farm equipment.

The following indicates conditions to be considered in spacing terraces. The trend for corn is to 30-inch rows and to 6- and 8-row equipment. One trip through the field takes either 15 or 20 feet. Many farmers are changing to 30-inch equipment, especially for the gentle slopes. Four-row, 40-inch equipment is being used on the steeper land but it will undoubtedly be replaced by 30-inch equipment, probably 6-row. In any event, the equipment being used and to be used should be considered in each layout. If the technician plans a spacing which will accommodate several row spacings, the system will be more flexible and much more valuable. If two different row crops with different row spacings are planned in rotation the layout should accommodate both row spacings.

Table 8-1 Terrace spacing for 30- and 40-inch equipment

40-inch Width rows			30-inch Width rows		
Number of rows	Trips - 4-row	Distance (feet)	Number of rows	Trips - 6-row	Trips - 8-row
18	4+	60	24	4	3 1/
22 2/	5+	75	30	5	--
24	6	80	32	--	4
28 3/	7	90	36	6	--
30	7+	100	40	--	5
32 4/	8	105	42	7	--
36	9	120	48	8	6
44 5/	11	150	60	10	--
48	12	160	64	--	8
56 6/	14	180	72	12	9
72	18	240	96	16	12

A trip means once through the field.

1/ It is not anticipated that 8-row 30-inch equipment will be used on land which is 10 percent and steeper, nor on terraced land with spacings less than 80 feet.

2/ Leave an extra 4 inches between trips to increase the spacing from 73.3 to 75.0 feet.

3/ Save 7 inches between trips to decrease the spacing from 93.3 to 90 feet.

4/ Save 3 inches between trips to decrease the spacing from 106.7 to 105.0 feet.

5/ Leave an extra 4 inches between trips to increase the spacing from 146.7 to 150.0 feet.

6/ Save 6 inches between trips to decrease the spacing from 186.7 to 180.0 feet.

Table 8-1 shows possible terrace spacings which will fit 30- and 40-inch row equipment. Some adjustments are necessary and these have been made on the 40-inch rows because there is more flexibility with the 40-inch row pattern. First of all it takes more trips (one pass through the field) with 4-row, 40-inch equipment than it does with 6- and 8-row, 30-inch equipment. The only place to adjust is in the spacing between trips, thus the more trips between terraces the more opportunity to adjust. Secondly, 40-inch rows can be narrowed 6 to 8 inches without difficulty. This is not feasible with 30-inch rows, considering the equipment and the width of tractor tires. It should be noted in the table that the 120-foot spacing fits all the equipment shown.

7. ALIGNMENT

Alignment is probably the most important factor in terrace farmability and acceptance. Terraces should be parallel wherever possible for row crops. When this is not possible due to topography or other reasons they should be laid out with the best possible alignment. When all the terraces in a field will not lay out parallel, divide the system up into groups of parallel terraces. Generally, terraces which are straight or nearly straight with gentle curves are easiest to parallel and to farm. Likewise terraces which have many curves, sharp curves, and reverse curves are difficult to parallel and more difficult to farm.

On short slopes or fairly regular slopes all terraces can be made parallel if soil conditions permit. On long slopes or irregular slopes it may not be possible to do this. Correction areas may be necessary, but these areas can be concentrated between groups of parallel terraces. They can be planned as to width so that they also will fit the farm equipment.

CORRECTION AREAS

Correction areas warrant detailed study to provide the best farmable terrace system. There are two general considerations to be kept in mind:

1. Confine corrections to the area between groups of parallel terraces.
2. Use one large area instead of several smaller ones.

If a correction area is small and narrow, do not correct at this point. Rather, adjust one of the sets of parallel terraces to eliminate the small correction area. This will have one of two effects. It may eliminate the correction area entirely as the group is adjusted down the slope or it will result in a wider and more usable correction area.

Generally farmers tend to plow and plant the whole field including the correction areas. When the correction areas are farmed it is necessary to turn on the crop and thus cause some damage. Correction areas can be left in grass, or portions of the area left in a grass turn strip to eliminate turning on the crop. If a small, narrow correction area is necessary it should be left in grass.

Long, narrow correction areas, as well as short, narrow areas, are very difficult to farm, especially during cultivation and harvest. Therefore the more small areas that can be concentrated into large areas the better the system will be for farming.

On fields which have major changes in slope from one end to the other, the horizontal spacing between two terraces may have to be adjusted in order to stay with the approximate contour. For example, the spacing may change from 24 rows at one end to 32 rows at the other. Here the change fits 4-row equipment as it accounts for one round trip of extra rows. An example of this is shown in Figures 8-79 and 8-80.

POINT ROWS

Keeping point rows out of the terrace system is one of the main aims in layout. It is not always possible to eliminate point rows. But if the number can be reduced to the fewest possible the terrace system will be more farmable.

Several methods of planning to eliminate point rows or to confine them into large correction areas, have already been discussed. However, one important factor regarding point rows should be kept in mind. Point rows introduced into a system at one point usually will cause complementary point rows at two other locations. Generally, terrace lines are fairly smooth and straight at the top of a hill. Likewise, they are fairly straight along the base of a hill. Usually, the line at the top of a hill will be fairly parallel to the line at the base of the hill. The simplified illustration in Figure 8-21 shows a 3-terrace layout and what happens if a line between the top and the bottom has a sharp curve in it.

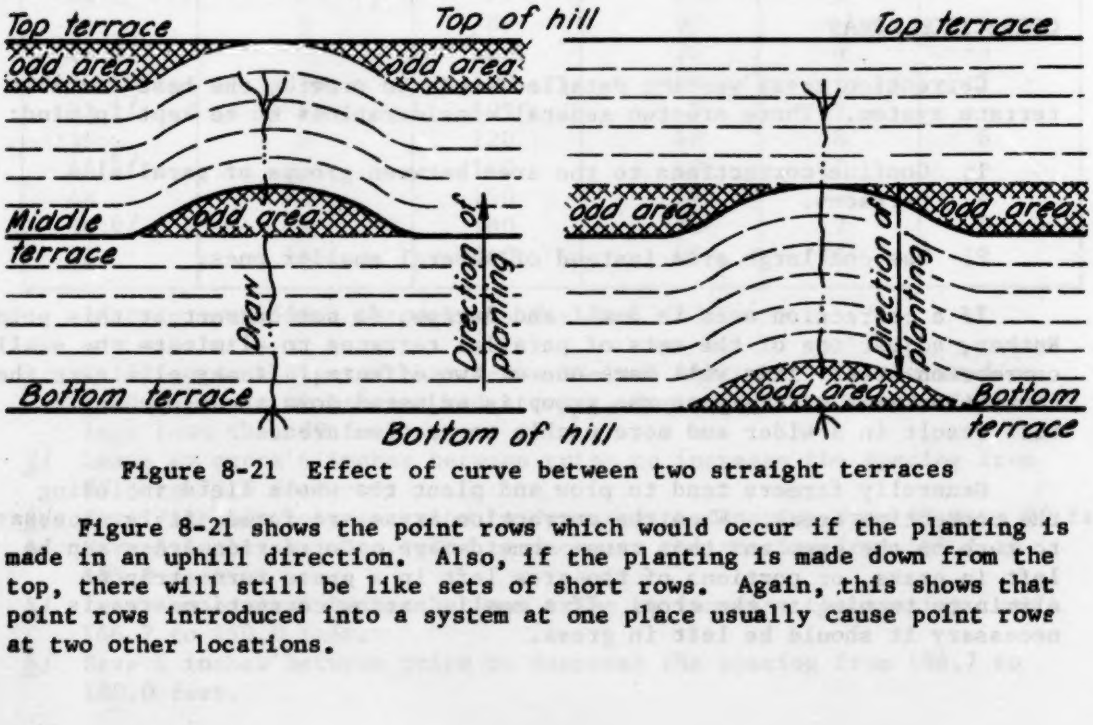


Figure 8-21 Effect of curve between two straight terraces

Figure 8-21 shows the point rows which would occur if the planting is made in an uphill direction. Also, if the planting is made down from the top, there will still be like sets of short rows. Again, this shows that point rows introduced into a system at one place usually cause point rows at two other locations.

In the above illustration about the only solution would be to fill across the depression to straighten out the middle lines. This might be a good location for a tile outlet.

GENERAL GUIDES FOR PARALLELING

There are several methods or guides available for paralleling terraces. Often a combination of these methods is necessary to make a group of terraces parallel.

Cut and Fill Along the Terrace Line

This is one of the best methods of improving alignment. It simply means cutting at the high points and filling at the low points in order to keep the alignment straight or smooth. It works well on the flatter topography, as small cuts and fills will allow the lines to be made parallel. It works with all types and cross sections of terraces. The terrace can be made to go straight across the smaller depressions and draws. See Figure 8-22. A method of cut-and-fill design is discussed under the section on design.

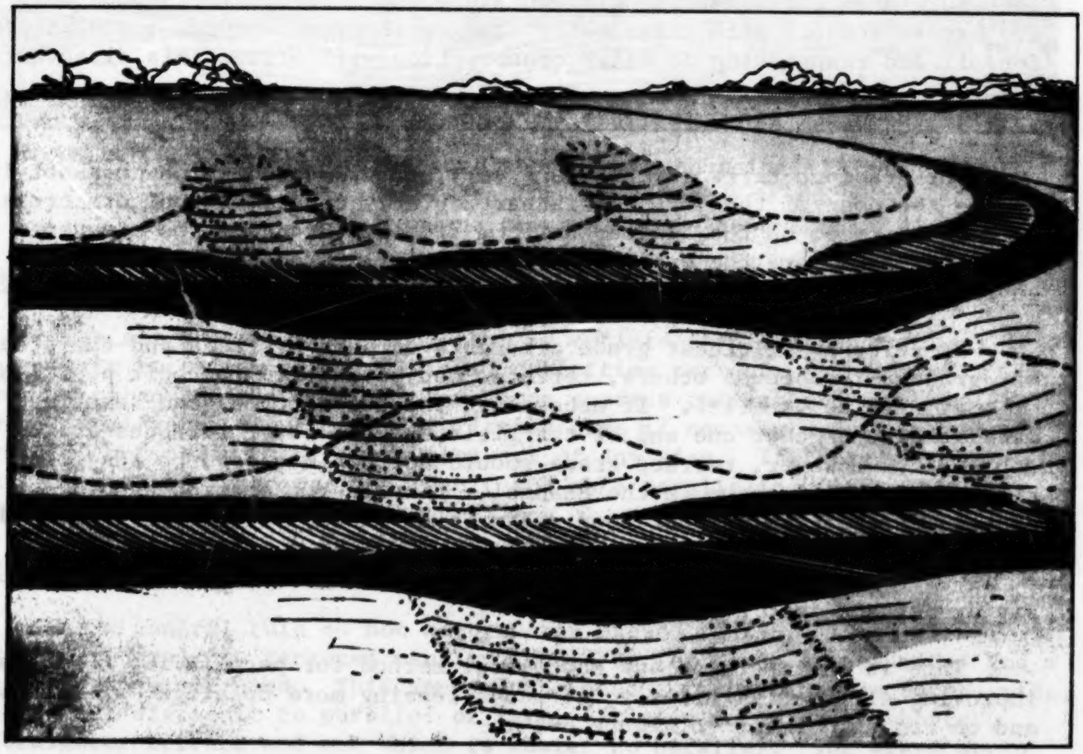
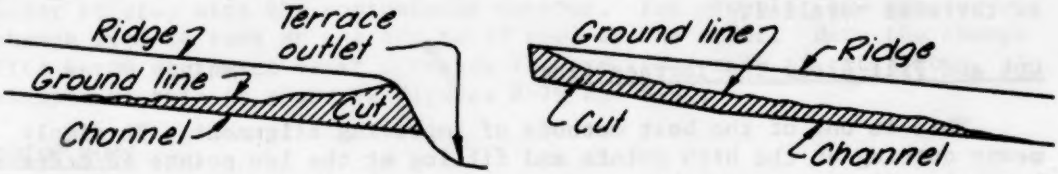


Figure 8-22 **Making terraces parallel by cutting and filling (dashed lines show where standard terraces would have been)**

Cutting and filling have other advantages. The terrace grade can be increased by cutting at the lower end and filling at the upper. Grade can be decreased by filling at the lower end and cutting at the upper. See Figure 8-23. The grade also can be made uniform by cutting and filling. Waterways and grass turn strips can sometimes be eliminated by using the cutting and filling procedure.



Cutting on Lower End to Increase Grade and Straighten Terrace

Cutting on Upper End to Decrease Grade and Straighten Terrace

Figure 8-23 Increasing and decreasing grade by cutting

There are limitations to consider in cutting and filling. Terraces cost more when earth has to be moved along the terrace line. Deep cuts may expose subsoil with unfavorable characteristics. However, stockpiling topsoil and respreading it after construction will offset this disadvantage.

Varying the Grade Along the Terrace

For gradient terraces this is a very useful method which does not increase the cost of the job. It is particularly adapted to uniform cross-section terraces on the flatter uniform slopes. Grade can be steepened at the upper end where the drainage area is small. Grade can be flattened anywhere along the line.

By using the flattest grade allowable on some terraces and the steepest grade allowable on others, terraces can be shifted in their positions so they will be parallel. If necessary, the top terraces can sometimes be made to discharge at one end of the field and the lower terraces at the other end. However, terrace grade should not be increased to the point that erosion will occur in the channel. Likewise, the grade should not be flattened to the point that poor drainage or excessive deposition of sediment will result.

Divide Terrace into Short Segments

This is an important and economical method for paralleling terraces or improving alignment. Briefly, it means leaving more openings, at waterways and on ridges. Refer to Figure 8-24.

Where terraces are divided into shorter segments, there are several advantages. Since the sections are short, the grade can be varied to allow more flexibility in layout. Less cut and fill will be needed. Thus, more terraces can be made parallel. Equipment can be turned on grass at ridges and field boundaries instead of turning in cropland. And, the grassed areas other than waterways provide travel roads for equipment.

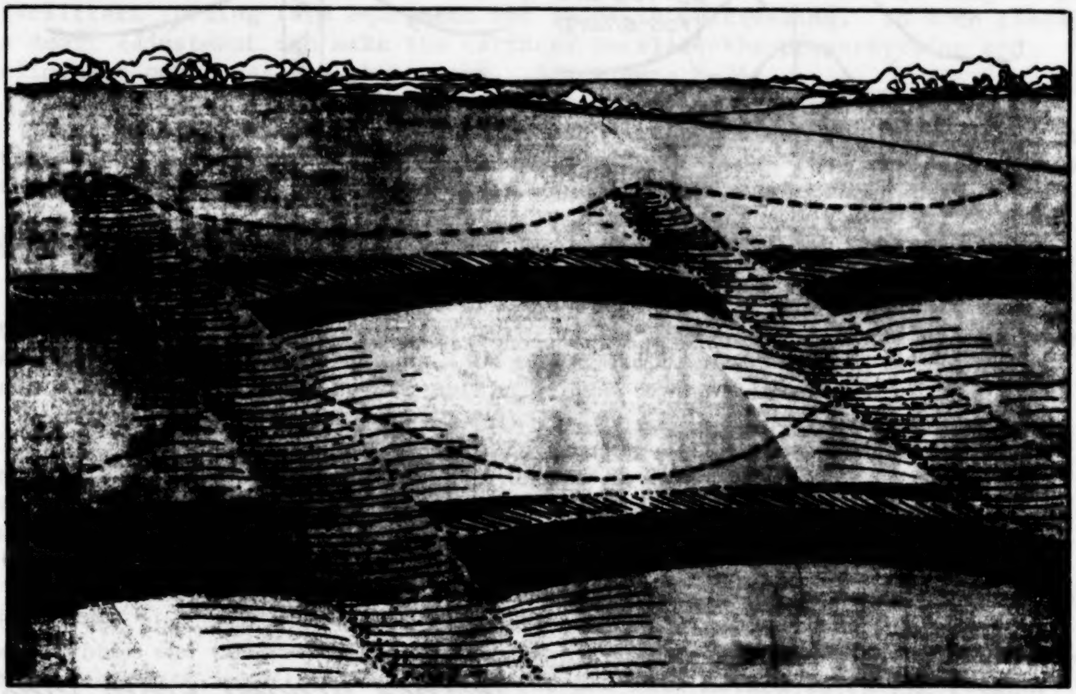


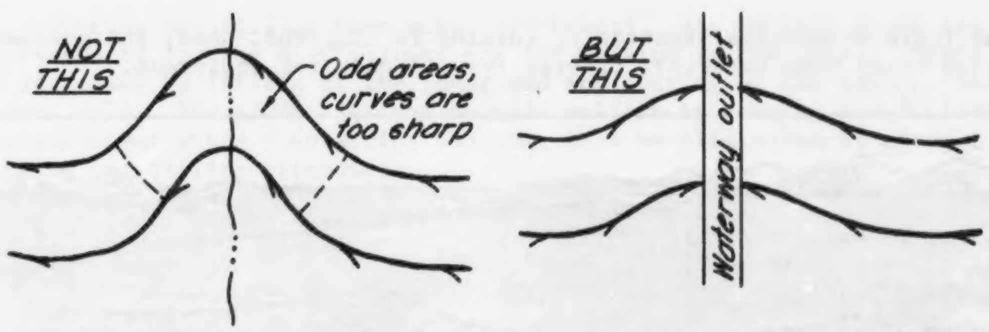
Figure 8-24 Divide into short segments using all the waterways (Dashed lines show where standard terraces would have been)

Waterways

Use all the waterways and draws as outlets for gradient terraces if necessary to obtain parallel lines, outletting terraces into either a waterway or an underground outlet. Where surface outlets are used, build additional waterways or deepen existing ones if necessary. As a general rule do not carry water past waterways of any size. If large waterways are crossed sharp curves may result and make paralleling difficult. See Figure 8-25.

Ridges

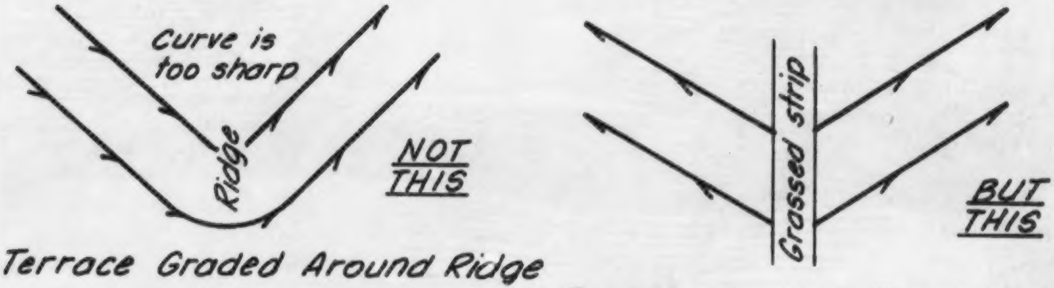
As a general rule do not carry water around ridges. If the ridge is narrow (sharp) the terraces usually should be left open at the ridge and a grass turn strip used. This removes the need for sharp curves on the ridge which are difficult to parallel or farm. It also makes for a shorter, straighter terrace and one which is easier to parallel. The grass strip should be wide enough so that the terrace can come straight into the strip and all turning of equipment can be done on the grass strip. See Figure 8-26. Grass strips on the ridges provide an ideal location for farm roads.


NOT THIS
Odd areas, curves are too sharp
BUT THIS
Waterway outlet

Terrace Graded Past the Waterway

Waterway Used as Outlet

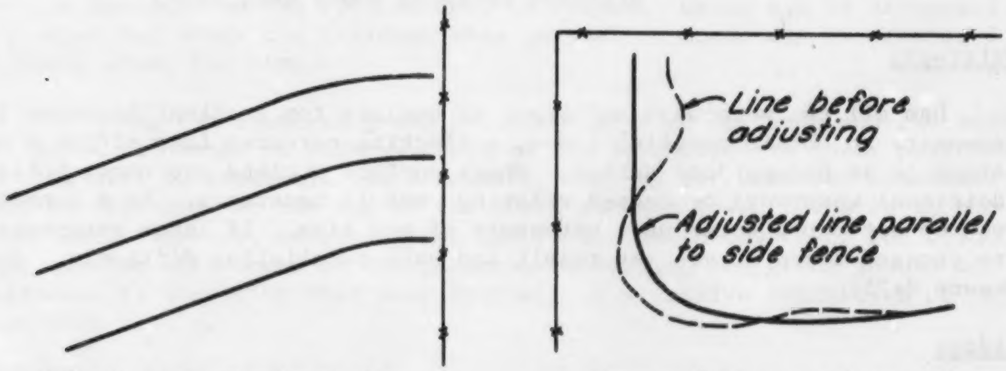
Figure 8-25 Right and wrong layout at waterways


Curve is too sharp
Ridge
NOT THIS
Grassed strip
BUT THIS

Terrace Graded Around Ridge

Terrace Graded From Ridge

Layout at ridges


Line before adjusting
Adjusted line parallel to side fence

Terraces Curved to Approach Fence as Nearly Perpendicular as Possible

End of Terrace Made to Parallel Fence

Layout at field edge

Figure 8-26 Layout at ridges and edge of fields

Layout at Edge of Fields

Terraces should approach the edge of a field at nearly right angles to facilitate turning farm equipment and help in cultivating. In some cases, a small adjustment can make the terraces parallel the property line and eliminate odd areas and short rows. See Figure 8-26.

It is often desirable to leave a turn strip between the end of the terrace and the field boundary. Turning usually destroys the crop growing near the field boundary. The grass strip can also serve as a field road.

GRADIENT TERRACES WITH WATERWAY OUTLETS

Paralleling this type of terrace system generally is more difficult than paralleling graded terraces with underground outlets or level terraces, except on smooth gentle slopes. On rough slopes, the use of all methods available may be necessary to obtain groups of parallel terraces.

Dividing the terraces into short segments is probably the best technique for paralleling gradient terraces with waterway outlets. By using most or all of the available draws for outlets and varying the grade along the terraces it usually is possible to make them parallel.

If these two methods do not give the desired results, cutting and filling along the line will allow more adjustment. This will make the lines straighter and the curves less sharp, which makes paralleling easier. However, the most important use of the cut-and-fill method is on the rougher land. It also can be used to eliminate some of the minor outlets by filling straight across some of the natural waterways.

The following guidelines should be kept in mind. Do not carry water around short ridges. Eliminate sharp curves at such locations by using grass turning strips that can serve as field roads. When curves are necessary, make them long and gradual. If at all possible, eliminate reverse curves. Follow the methods discussed above for making the layout at the edge of fields.

GRADIENT TERRACES WITH UNDERGROUND OUTLETS

This type of terrace system promotes parallel alignment because terraces can be built straight across the shallow waterways and draws.

The cut-and-fill method is especially adapted to terraces with underground outlets as fills are necessary when depressions are crossed. Cuts generally are needed on the broad ridges, so this provides a natural place for borrow. By crowding the terrace up on the ridges and down in the waterways, lines are straightened and made easier to farm. Varying the grade also will help straighten the lines and reduce the cut and fill.

Leave sharp ridges open. If deep waterways or depressions are encountered, it may be better to develop a grass waterway to prevent a radical change in alignment. The layout at the edge of the field is also important.

Outlets should be developed as necessary to improve alignment. If tile lines have been installed in depressions for drainage, the inlet would add little extra cost. However, the tile line should be checked for excessive velocities that may occur when surface water is added to the line. Installation of a new tile line for an outlet may be cheaper over the years than accepting a poor alignment and a less farmable system.

Sometimes it is possible and advisable to use the two types of outlets for the same terrace, or for different terraces in the system, to obtain the best layout. Also there may be situations where there is too much fall in the terrace line. In these cases the higher sections of the terrace should be designed as a graded terrace discharging into the level or lightly graded storage part of the terrace.

LEVEL TERRACES

The same techniques used for paralleling gradient terraces can be used with level terraces, except the use of multiple outlets.

Cut and fill along the terrace line is almost a necessity with level terraces if a farmable alignment is to be provided. Since a level terrace has a level ridgetop and should have a reasonably level channel, earthmoving along the line will be necessary whenever the terrace is moved from the original contour line. This practice gives flexibility to the layout and permits more terraces to be parallel.

Leave openings at the sharper ridges. Generally, waterways are crossed by level terraces. However, at the deeply incised waterways, or where two major slopes intersect, it may be better to leave an opening. This is because terraces change directions rather radically at these intersections. These openings promote parallel alignment and, when grassed, can be used in the field road system.

The layout at the edges of fields and near farm boundaries are important also. Oftentimes a small adjustment here will allow parallel rows between the terrace and the fence. The end of the terrace may be either raised or blocked. The raised end is accomplished by raising the terrace line about one foot vertically at the end of the end of the terrace. This usually makes the terrace curve uphill and may make for difficult paralleling because of added short curves. The blocked end is accomplished by carrying the terrace out on the contour, and by building an earth block at right angles across the end of the terrace channel. This usually causes fewer alignment problems. See Figure 8-27.

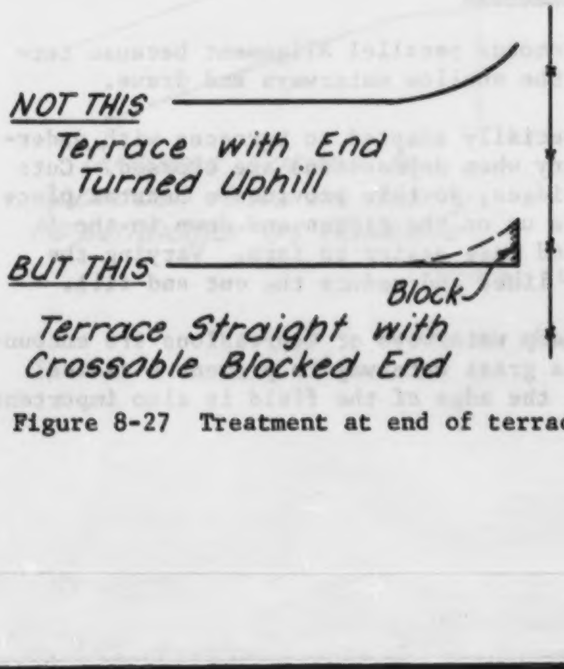

NOT THIS
Terrace with End Turned Uphill
BUT THIS
Block
Terrace Straight with Crossable Blocked End

Figure 8-27 Treatment at end of terrace

There is one additional technique that is adapted to only level terraces. It is a design method of dividing the terrace into various levels. The terrace will be continuous but the different levels of ridge and channel are separated by farmable earth blocks. Blocks, large enough to prevent individual rows from draining runoff into the depressed terrace segment, should extend the full terrace interval. Each of the different levels of the terrace should be designed as an individual level terrace, using its own level, even though the terrace is continuous. See Figure 8-28.

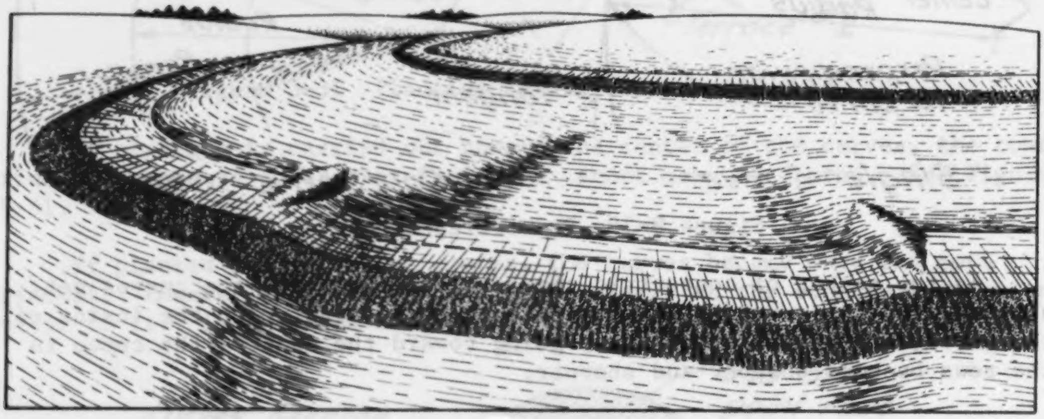


Figure 8-28 Dividing terrace into various levels

This feature promotes parallel alignment; a part of the terrace otherwise would have to be shifted to keep near the contour. This also prevents the excessive earthmoving that would be necessary to bring the entire terrace to one grade. The limitation of this method is that the different levels of the terrace must be separated by earth blocks. These must be maintained, and they are not easy to farm over with large machinery. Therefore, the more gradual the side slopes on the blocks, the easier they will be to farm.

8. LAYOUT GEOMETRY

Rather than proceeding right into layout, it is best to first consider some of the geometry of layouts. The geometry involved is not complex, dealing mostly with curves and straight lines, but it is often not recognized in a field layout.

CURVES

Most terrace systems have curves in them that are either simple or reverse curves. Simple curves are those which curve in only one direction. Reverse curves are two adjacent curves that curve in opposite directions. The reverse curve should be avoided if at all possible.

Parallel Curves

Each curve has a center. Concentric circles are parallel and have a common center. Concentric curves are portions of concentric circles so they, too, are parallel and have a common center. A perpendicular line drawn from a tangent on a curve will intersect the center and form a radius of each circle. Refer to Figure 8-29.

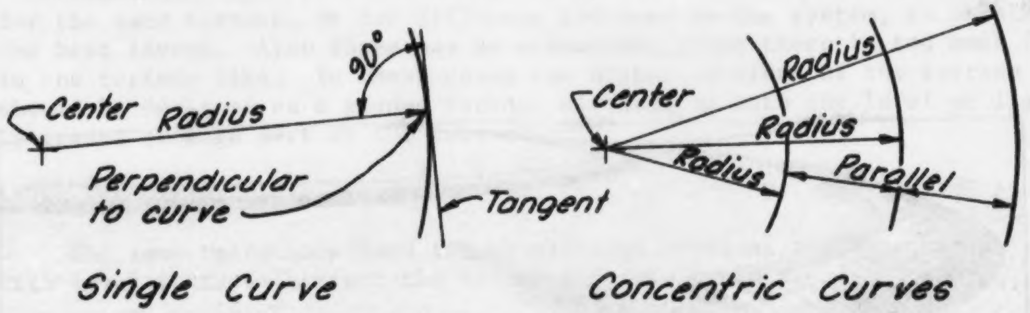

90°
Center
Radius
Perpendicular to curve
Tangent
Single Curve
Center
Radius
Radius
Radius
Parallel
Concentric Curves

Figure 8-29 Properties of curves

As the center of concentric circles is approached, the curves get sharper. In other words, if a terrace is being planted on the inside of the curve, and planting continues going toward the center, the curve in the rows becomes sharper and sharper.

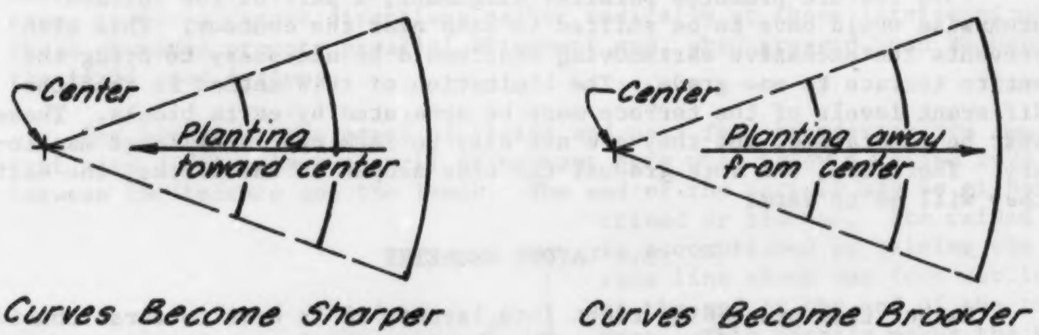

Center
Planting toward center
Curves Become Sharper
Center
Planting away from center
Curves Become Broader

Figure 8-30 Planting on curves

Identical Curves

Identical curves are curves of the same radius. One could be transposed on top of another and they would be exactly the same. If two adjacent terrace lines are laid out with curves of the same radius, point rows or odd areas will be created. This is most apt to happen on sharp ridges, although it also can happen at waterways. The following figures show this situation.

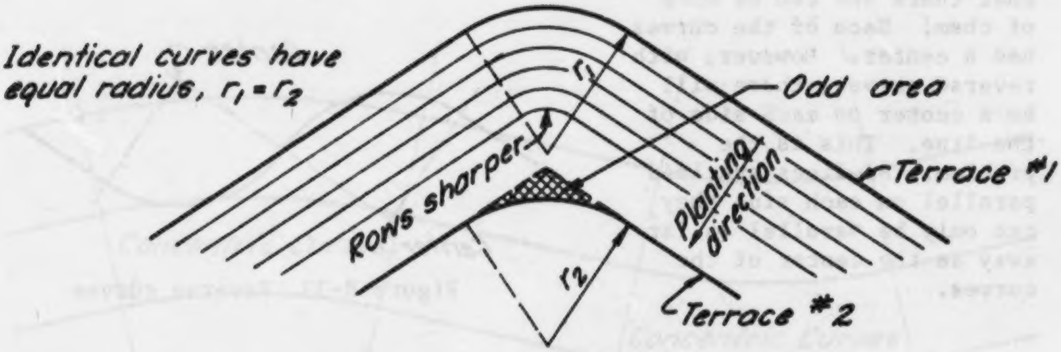

Identical curves have equal radius, $r_1 = r_2$
r_1
Odd area
Rows sharper
Planting direction
Terrace #1
r_2
Terrace #2

Figure 8-31 Planting toward center of curves

If planting is carried out toward the center of the curves, the rows finally become so sharp that equipment cannot make the turns. See Figure 8-31.

If planted away from the center, the curves become more and more gradual. However, point rows will be necessary at the outside terrace in order to fill in the remaining area. See Figure 8-32.

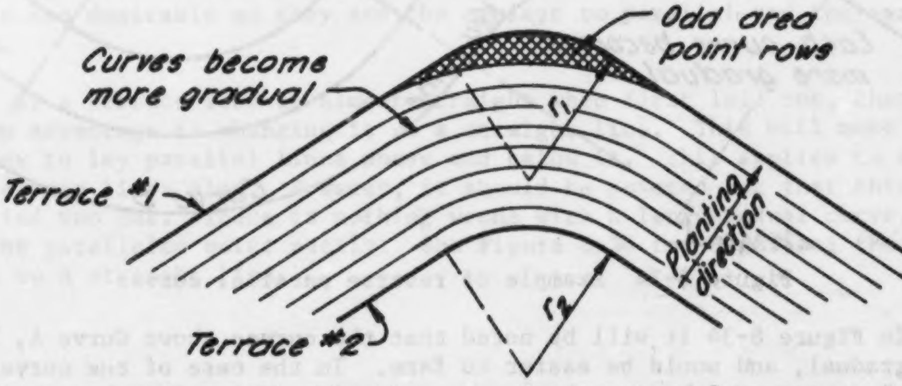

Odd area point rows
Curves become more gradual
r_1
Terrace #1
Planting direction
r_2
Terrace #2

Figure 8-32 Planting away from center of curves

Therefore, where curves are necessary they should not be identical. They should be laid parallel by making them an equal distance apart. They will then be portions of concentric circles with a common center. If this cannot be done, there will be point rows in the layout. Other techniques, described later, may be used to avoid using the curves.

Reverse Curves

A reverse curve occurs when a line curves first to the right and then to the left, or vice versa. Reverse curves occur quite often in terrace layouts. They should be avoided if possible. In any event, they should be recognized as a problem and given special attention. See Figure 8-33.

They are like the curves discussed earlier, the main difference being that there are two or more of them. Each of the curves has a center. However, with reverse curves, there will be a center on each side of the line. This is the problem. As lines are laid parallel on each side they can only be parallel as far away as the center of the curves.

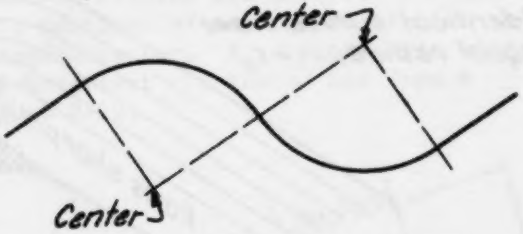


Figure 8-33 Reverse curves

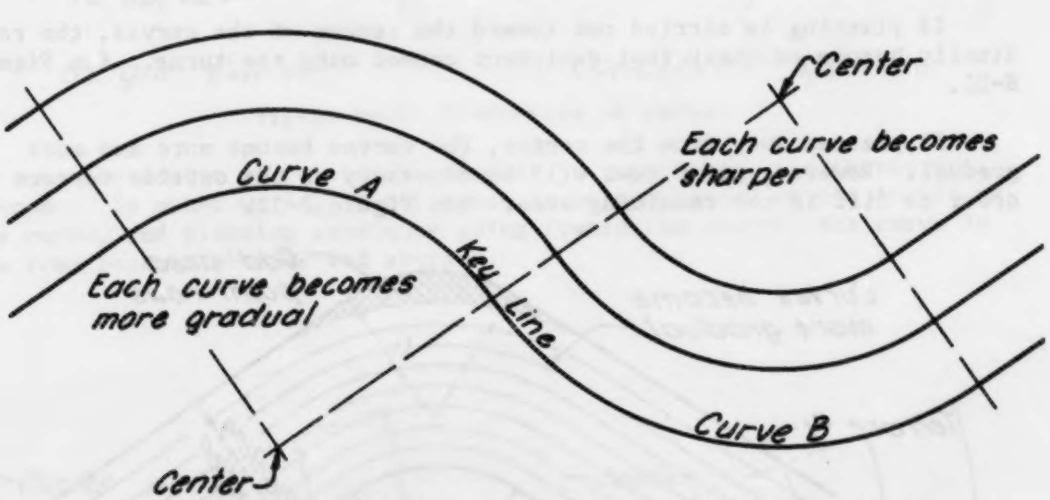


Figure 8-34 Example of reverse parallel curves

In Figure 8-34 it will be noted that the curves above Curve A, become more gradual, and would be easier to farm. In the case of the curves above Curve B, the curves become sharper toward the center. Somewhere before the center is reached there will be difficulty in farming because the curve of the rows will be too sharp. This shows that reverse curves limit the number of lines which can be made parallel on either side of the key line. If reverse curves cannot be avoided they should be planned as gradual curves. This places the center a greater distance away from the line, and should allow paralleling for a greater distance. Refer to Figure 8-35. If the curves cannot be made gradual, a correction area will have to be planned in the system.

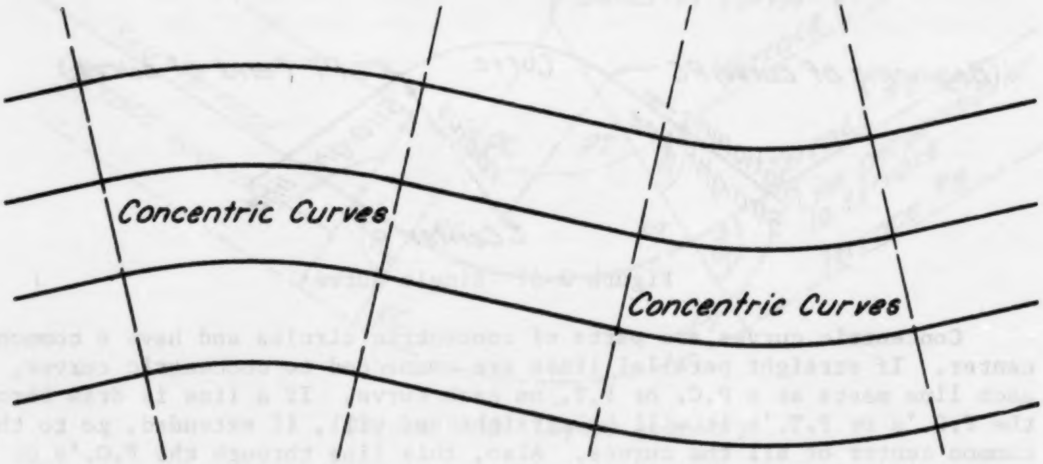


Figure 8-35 Reverse curve made gradual

STRAIGHT LINES

Segments of terraces will be composed of straight lines. Straight lines are desirable as they are the easiest to parallel and the easiest to farm.

If a terrace line is almost straight when first laid out, there will be an advantage to changing it to a straight line. This will make it easier to lay parallel lines above and below it. This applies to segments of terrace lines also. However, it should be pointed out that this can be carried too far. There is nothing wrong with a long gradual curve, as it can be paralleled quite easily. See Figure 8-36 for adjusting the stake line to a straight line.

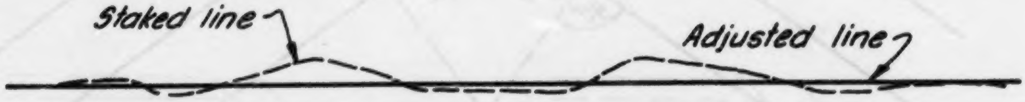


Figure 8-36 Changing staked line to straight line

CURVES AND STRAIGHT LINES

There will be many cases in layout where sections of terrace lines will be straight with curves connecting the straight lines. The point where the straight line meets the curve is the beginning of the curve and is called the point of curve or P.C. Likewise, the point where the curve meets the straight line is the end of the curve and is called the point of tangency or P.T. These are shown in Figure 8-37.

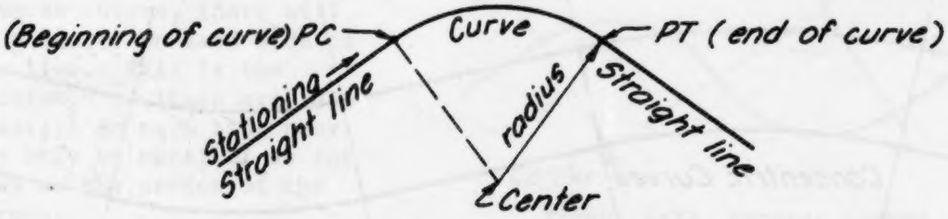

(Beginning of curve) PC
Curve
PT (end of curve)
Stationing
Straight line
radius
Straight line
Center

Figure 8-37 Single curve

Concentric curves are parts of concentric circles and have a common center. If straight parallel lines are connected to concentric curves, each line meets at a P.C. or P.T. on each curve. If a line is draw through the P.C.'s or P.T.'s it will be straight and will, if extended, go to the common center of all the curves. Also, this line through the P.C.'s or the P.T.'s will be perpendicular to the parallel lines. Refer to Figure 8-38.

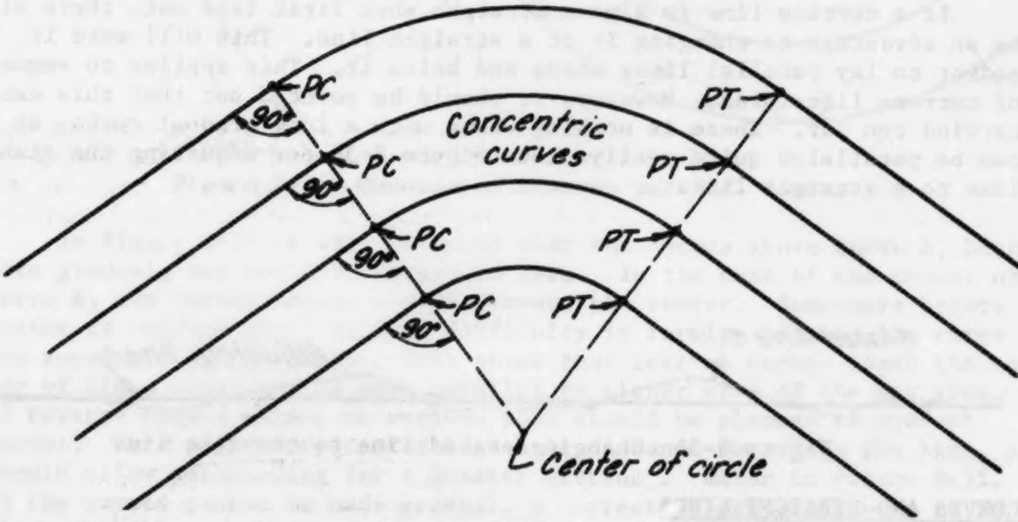

PC
PT
90°
Concentric curves
Pc
PT
90°
PC
PT
90°
PC
PT
90°
Center of circle

Figure 8-38 Parallel lines and curves

These factors are helpful in terrace layouts where curves are necessary between straight lines. Lining up the P.C.'s and P.T.'s on each terrace line and setting stakes at these points will save time in laying out the straight parallel segments. This will also set the length of each curve and assure that the curves are concentric and parallel.

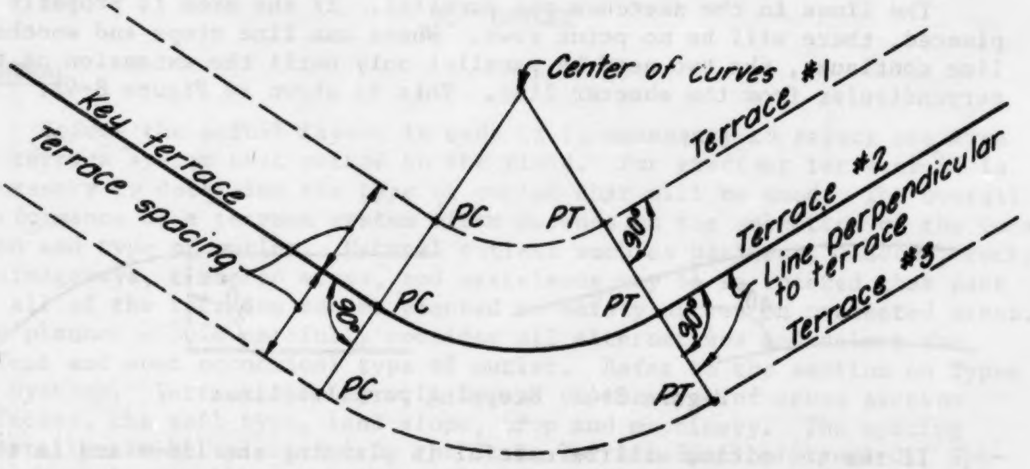

Center of curves #1
Terrace
Key terrace
Terrace spacing
PC
PT
90°
PC
PT
90°
90°
PC
PT
90°
Terrace #2
Line perpendicular to terrace
Terrace #3

Figure 8-39 Layout geometry

Referring to Figure 8-39, the P.C.'s and the P.T.'s are lined up by laying off a line each way from the key terrace and perpendicular to it. The P.C. and P.T. stakes for terraces 1 and 3 are set on the perpendicular line at the required spacing from the key terrace. The curves on terraces 1 and 3 can then be staked parallel to the curve on the key terrace. It will be noted that the curves become longer and more gradual from terrace 1 to terrace 3. The curve on terrace 1 is the sharpest and it must be checked to see that it is not so sharp as to interfere with cultivating and harvesting equipment.

EXTENSION OF PARALLEL LINES

One of the most valuable techniques in parallel terrace layout is that of stopping certain lines and extending other lines. If this is not considered at layout, point rows will generally occur where terraces abut grass strips, waterways and roads. The sketches in Figure 8-40 demonstrate this technique.

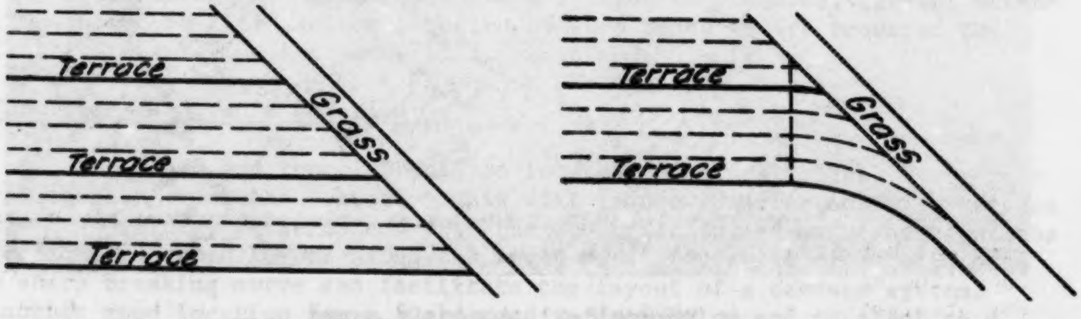

Terrace
Terrace
Terrace
Grass
Terrace
Terrace
Grass

Figure 8-40 Extension of parallel lines

The lines in the sketches are parallel. If the area is properly planted, there will be no point rows. Where one line stops and another line continues, the two need be parallel only until the extension of the perpendicular from the shorter line. This is shown in Figure 8-41.

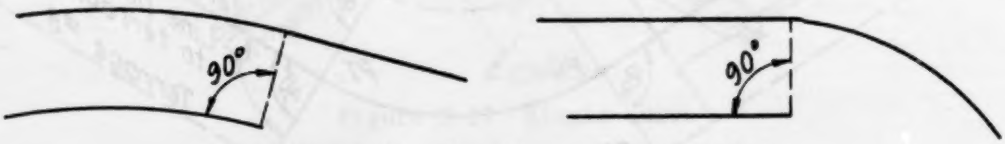


Figure 8-41 Stopping parallel lines

If the technician will be careful in planning the lines and in the use of grassed areas (as turnrows, waterways, or roads) many layouts can be made parallel which would be impossible otherwise. This is especially useful at ends of fields, and at openings at waterways and ridges. This is the only way a sharp ridge can be paralleled.

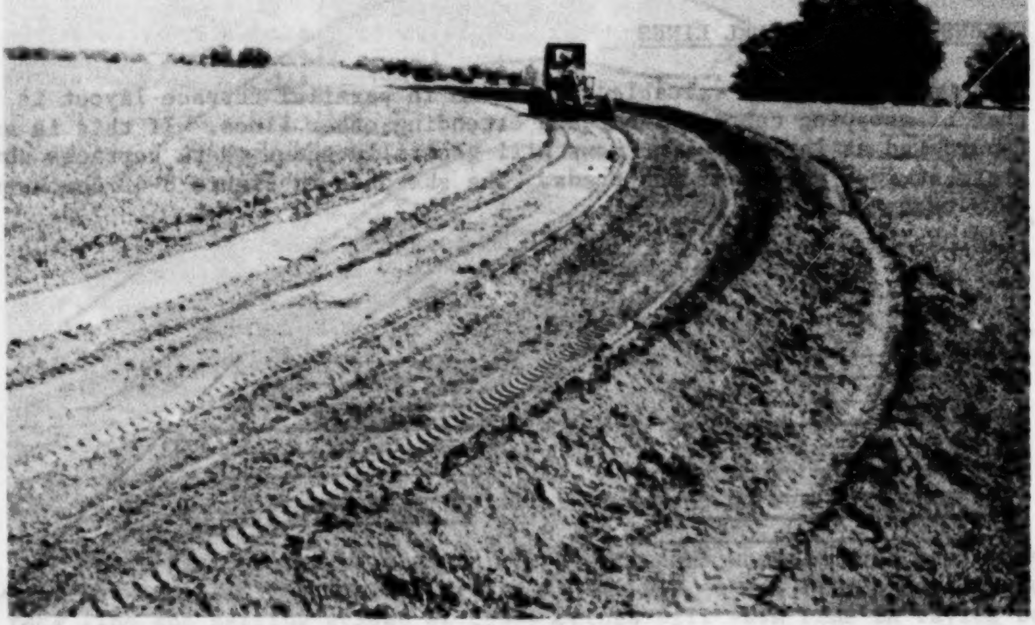


Figure 8-42 A gentle curve

9. LAYOUT

GENERAL

Before the actual layout is made it is necessary to select the type of terrace system best suited to the field. For gradient terraces it is necessary to determine the type of outlet that will be used. The overall performance of a terrace system often depends on the selection of the location and type of outlet. Natural outlets such as pastures, meadows, rocky drainageways, timbered areas, and wastelands may be so located that part or all of the terraces can be planned to safely outlet on protected areas. The planner should carefully consider all alternatives and select the safest and most economical type of outlet. Refer to the section on Types of Systems. Terrace spacing will depend on the type of cross section selected, the soil type, land slope, crop and machinery. The spacing generally can be selected from the State Terrace Spacing Standard. Specialty crops, such as orchards, will often affect spacing. Approximate field boundaries, field roads and fences should be determined prior to or at the time of layout.

Terraces in Orchards

The principles and design criteria for the planning of gradient terrace systems on rotated cropland also apply to orchards and vineyards. Tree rows are planted on each terrace ridge and thus the terrace spacing should be a multiple of the tree-row spacing within allowable limits. Where it becomes impractical to construct adjacent terraces parallel to each other, the long or continuous rows should be located parallel to the terraces with the short or point rows located in the center of the terrace interval.

In some areas it is an accepted practice to construct a terrace for each tree row. In such cases the tree-row spacing fixes the terrace spacing, usually at a distance of 25 feet or less. When the terrace spacing is so reduced, a corresponding reduction may be made in the settled cross-sectional area of the terraces, provided they will have a capacity adequate to accommodate the peak runoff that may be expected to result from a 10-year frequency storm without overtopping.

In planning the layout of terrace systems in orchards, careful attention should be given to the location of such roads as are required to facilitate spraying and harvesting operations.

Farm Roads and Fence Location

Farm roads and fences should be located on natural ridges where terraces crest or on the contour. This will reduce interference with terrace and row drainage patterns and with the construction and maintenance of the terraces. A road layout along the crest of a ridge will often eliminate a sharp breaking curve and facilitate the layout of a terrace system. Another good location for a field road is just below and parallel to a terrace ridge. A road is often used in the interval between two parallel systems and is located just below the upper terrace so it can also be used as a turning strip. If it is necessary to have a road on one side of the field it should be located so that it will cross on the closures at the closed end of the terraces. Fences or roads should never be located across the outlet ends of rows or terraces. Figure 8-43 shows parallel terrace systems with adjustment strips and an adequate farm road layout for safe and easy entrance to all terraces. Note land use changes to implement good terrace planning and layout.

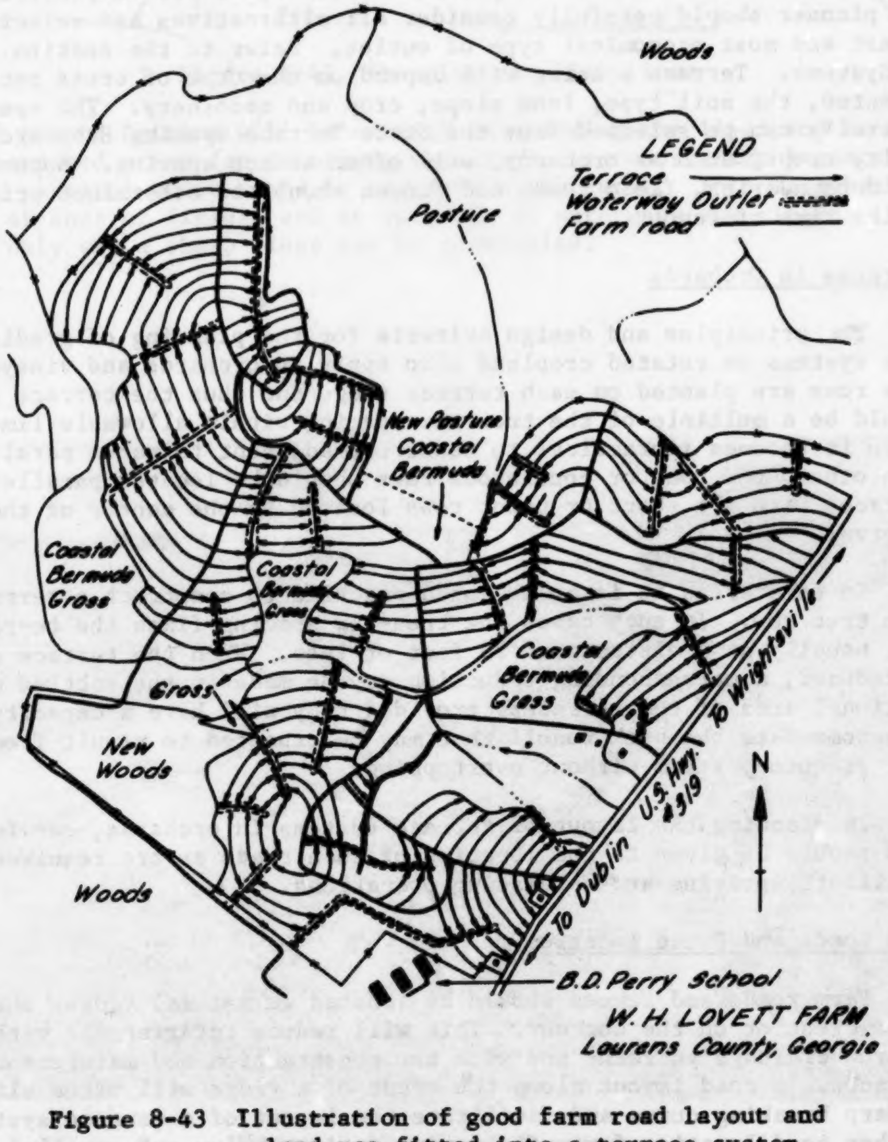

Woods
LEGEND
Terrace
Waterway Outlet
Farm road
Pasture
New Pasture
Coastal
Bermuda
Coastal
Bermuda
Grass
Coastal
Bermuda
Grass
Coastal
Bermuda
Grass
Grass
New
Woods
To Wrightsville
U.S. Hwy
#319
N
To Dublin
Woods
B.D. Perry School
W. H. LOVETT FARM
Laurens County, Georgia

Figure 8-43 Illustration of good farm road layout and land use fitted into a terrace system

Critical Areas

Critical areas are those with short, usually abrupt, and steep slopes that occur within a terraceable field. They should not be terraced but should be planted to adapted perennial vegetation. Terraces should be located immediately above and below these areas. If the width of a critical area, as measured normal to the terrace lines, is greater than the allowable terrace spacing, a diversion channel should be constructed immediately below the area. The design and construction of diversions is included in Chapter 9 of this manual.

Preliminary Surveys

The layout of a satisfactory parallel terrace system is more or less a cut-and-try procedure. It is generally necessary to move and adjust the first lines laid out in order to obtain the best farmable system. The amount of adjustment necessary often depends upon the experience of the technician and the topography of the field.

It is helpful to first make a physical inspection of the field. Location of suitable surface outlets can be noted. Waterways that have tile lines should be located. The inspection will show depressions and draws that will require terrace fill. If there are many draws and they are deep it would be best to fill and shape at least the deeper ones prior to layout and construction of the terraces.

Sufficient surveys should be made so that each terrace system can be properly planned. Detailed topographic information must be obtained before the best possible terrace systems can be designed or laid out. On small fields with short uniform slopes and well defined drainageways this information can be obtained from observation, random shots, and trial terrace lines. However, this procedure is time consuming and generally inefficient on large fields with uneven slope changes, slope reversals and many poorly defined natural depressions. These land features create complex terrace system design and layout problems. The use of a topographic map for the complex system or as a training aid for the inexperienced terrace planners will result in higher quality systems with better alignment, fewer point rows and more parallel terraces.

Topographic Maps

A reasonably accurate topographic map can be used effectively from the early planning stage of terrace system development through final construction. It can be used to work out the best terrace layout, better plan the correction areas, locate the required outlets, and develop the best field road system and turn strips. With a map showing the complete information on the field, the entire layout and how it fits together can be seen. It also allows design of segments of terraces on which corrections by construction may be made to improve alignment or to keep them parallel. Another important advantage is that the designer can explore all alternate layouts without time-consuming efforts in the field. The farmer can select the layout that best fits his needs and desires. The use of topographic maps permits planning and designing far in advance of construction and at times more convenient to the planner. After the selected layout has been developed, it can be staked in the field according to the paper layouts. Planning with a topographic map has a special advantage when only part of the system will be installed now and the remainder at some later date.

Types of Maps

A reasonably accurate topography map with good reference points should be prepared so that the paper layout can be easily staked in the field. Topographic maps for terrace planning are generally made by one of the following methods: (Refer to Chapter 1 for survey and plotting information).

Planetable or Transit--Contour lines are located in the field and plotted with planetable and alidade, or elevations of points and their location can be determined by transit and stadia. These points are later plotted in the office and contour lines interpolated. The contour interval depends upon the slope of the field ranging from 2 feet for the flat slopes to 4 or 5 feet for steeper slopes. Running a contour line and plotting it in the field is best adapted to steep, irregular slopes.

Grid Survey--This method is particularly adapted to the more even, flat topography but can be used on most slopes. It is easier to make with less equipment and gives an accurate map if care is used in interpolating the contour lines. With the grid it is easier to reference in the gridlines for transfer of the paper plan to the ground.

Stereo-Photogrammetric Plotting--This method saves on technical time and is probably the most economical way to obtain topographic maps for a large area where there are numerous requests or needs for terraces. Low altitude aerial photography is needed either for 2- or 4-foot contours usually used for terrace planning. Contour lines are then located by either a Kelsh or some other type of plotter. By using adequate control points the paper plan can be satisfactorily transferred to the field. These maps are adapted to any topography. Scheduling is important, as there are several steps necessary to develop Kelsh maps so it is best to plan on getting the maps in the fall, making the designs over the winter for layout the following season. It is best to be somewhat generous in requesting photography, in other words photograph adjoining areas though there is no apparent need on hand. Photography is a small part of the total costs, and ground control and plotting can be deferred until needed.

Planning with Map

Using the contour map, determine the design slope and terrace interval. Where practical, use the same spacing for all terraces in the field or for groups of terraces. Locate probable outlets and roads. Then lay in terraces to best fit the topography.

It is a good idea to place a plastic acetate sheet large enough to cover the field over the topographic map with the rough side up. The use of the plastic sheet will allow lines to be drawn and erased at will without damaging the design sheet.

Templates made from plastic sheets about 10 x 12 inches with parallel lines drawn on the sheets for different terrace intervals will assist the designer in fitting the terraces to the contours. It can be seen how many terraces can be made parallel before shifting to another group. Adjust templates to give what appears to be a satisfactory grade for the first segment of the flattest terrace and determine if the grades of the other terraces are satisfactory. If not shift template and recalculate. Use another template to extend lines for another segment in the same manner. Join the two segments with proper curves if necessary. Continue process until the end of terrace is reached. Select a template line as a guideline and be sure it can be referenced to the ground. With a pin or other sharp instrument mark a point through the template on each segment of the line and points of intersection. Then mark beginning and intersection of the other lines and draw the terraces on the plastic overlay. Elevations or rod readings can be calculated for all terrace lines where they cross gridlines. Transfer the terrace lines and elevations, location of outlets, turn strips and roads to the contour map when the system is completed to the designer's satisfaction.

Figure 8-44, sheet 1 of 2, is a grid survey of a field for use in parallel terrace system design and layout. Note location of grid stakes, rod readings, contour lines, reference points and other features. Sheet 2 of this figure shows a graded parallel terrace system with waterway outlet developed from the grid survey map in sheet 1.

Figures 8-45 and 8-46 are examples of terrace planning using topographic maps. Figure 8-45 shows groups of parallel terraces using tile outlets. Note correction areas. The parallel system shown in Figure 8-46 uses both tile and waterway outlets and has a well planned road system.

Field Layout from Map

The terrace system plan recorded on the topographic map can easily be transferred onto the land by using horizontal and vertical controls, if sufficient field references are established during the survey. When the landowner is ready to construct the terraces the technician, using the map locations and reference points, physically lays out key terraces on the ground. This is usually done by measuring from the key points with a minimum of actual survey instrument time. This line is checked and compared with design grades. The other terraces are staked above and below the key terrace at the determined interval.

Care must be exercised in staking the terrace lines so that they are equidistant at all locations for parallel terraces. This is generally done by one of two methods.

1. A tape, rope or similar apparatus equal in length to the horizontal spacing can be used if sufficient measurements are made and if care is taken to be accurate.

2. Spacing of terraces is planned for the farmer's equipment so a more accurate method is to use the farmer's tractor for marking terrace lines. The key line is first followed by the farm tractor

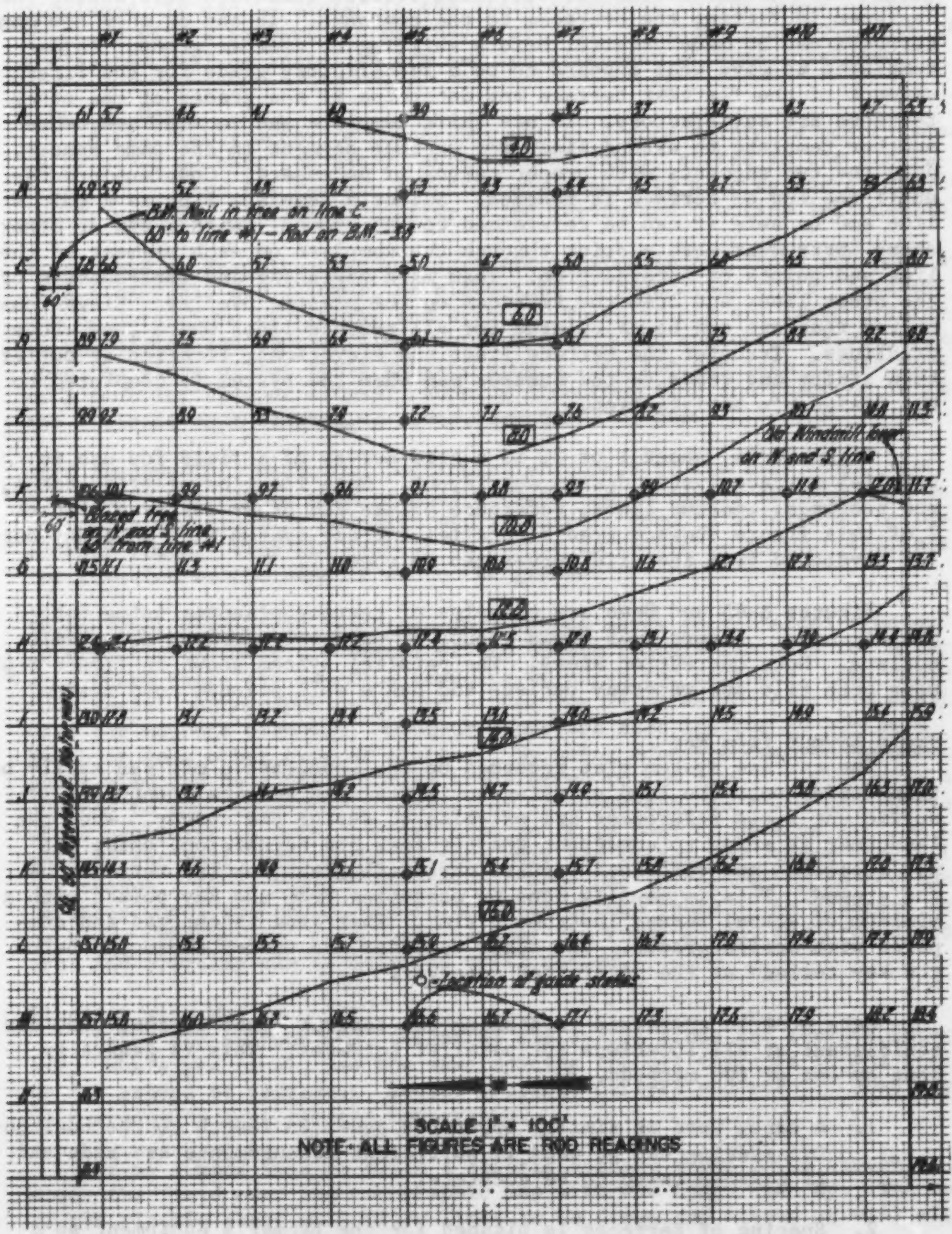

#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
A
B
C
D
E
F
G
H
I
J
K
L
M
N
30
60
90
100
120
140
150
B.M. Nail in tree on line C 60' to line #1 - Rod on B.M. -58
60'
Old Windmill tower on N and S line
Blazed tree on N and S line 60' from line #1
Location of guide stakes
SCALE 1" = 100'
NOTE - ALL FIGURES ARE ROD READINGS

Figure 8-44 Grid survey map for use in parallel terrace system design and layout

(Sheet 1 of 2)

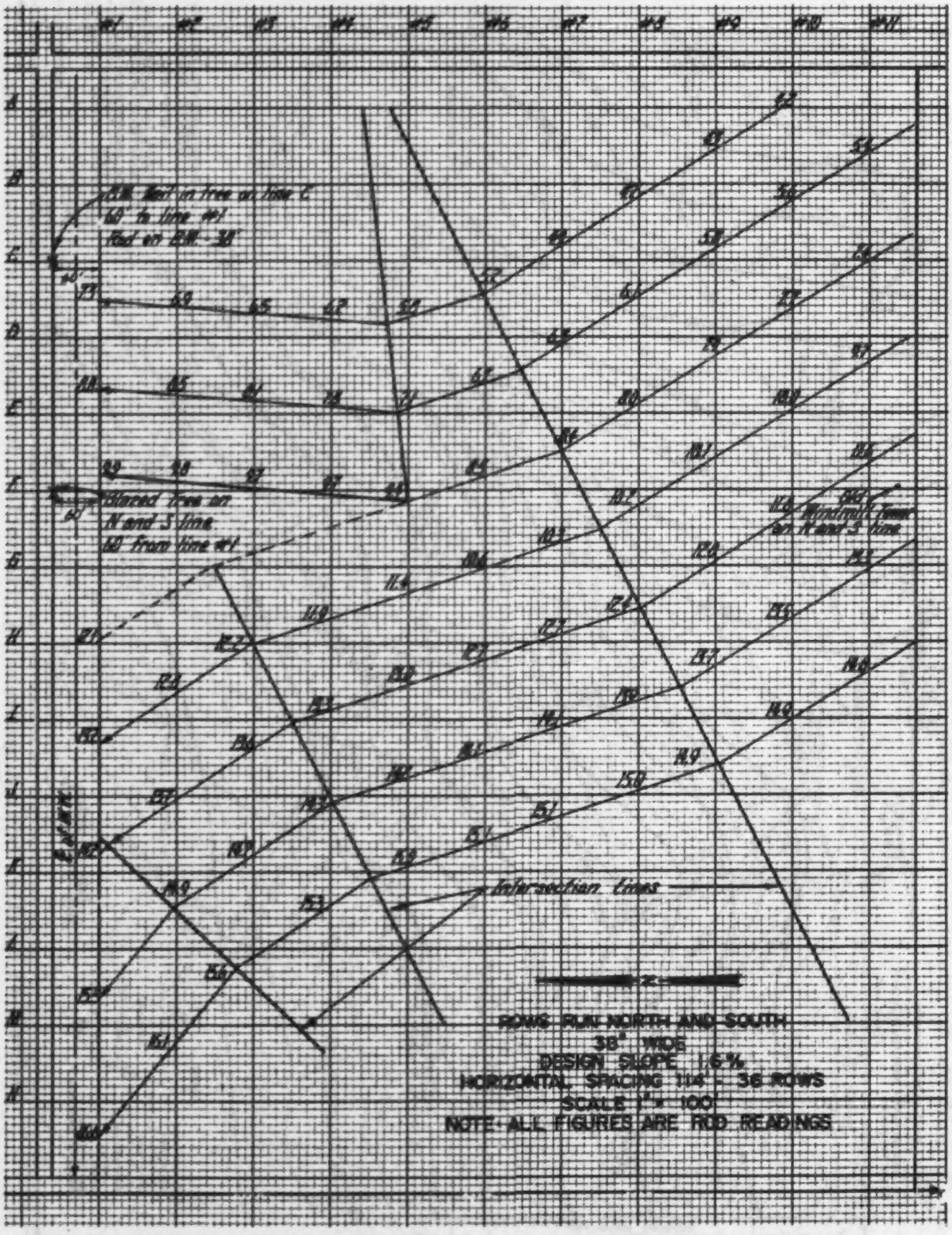

#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
A
B
C
D
E
F
G
H
I
J
K
L
M
N
B.M. Nail in tree on line C
60' to line #1
Rod on B.M. - 3.8'
Blazed tree on
N and S line
60' from line #1
Windmill tower
on N and S line
Intersection lines
N
ROWS RUN NORTH AND SOUTH
38" WIDE
DESIGN SLOPE 1.6%
HORIZONTAL SPACING 114' - 36 ROWS
SCALE 1" = 100'
NOTE: ALL FIGURES ARE ROD READINGS

Figure 8-44 Graded parallel terrace system design developed from grid survey map in sheet 1. Terraces outlet into existing waterway on north side of field

(Sheet 2 of 2)

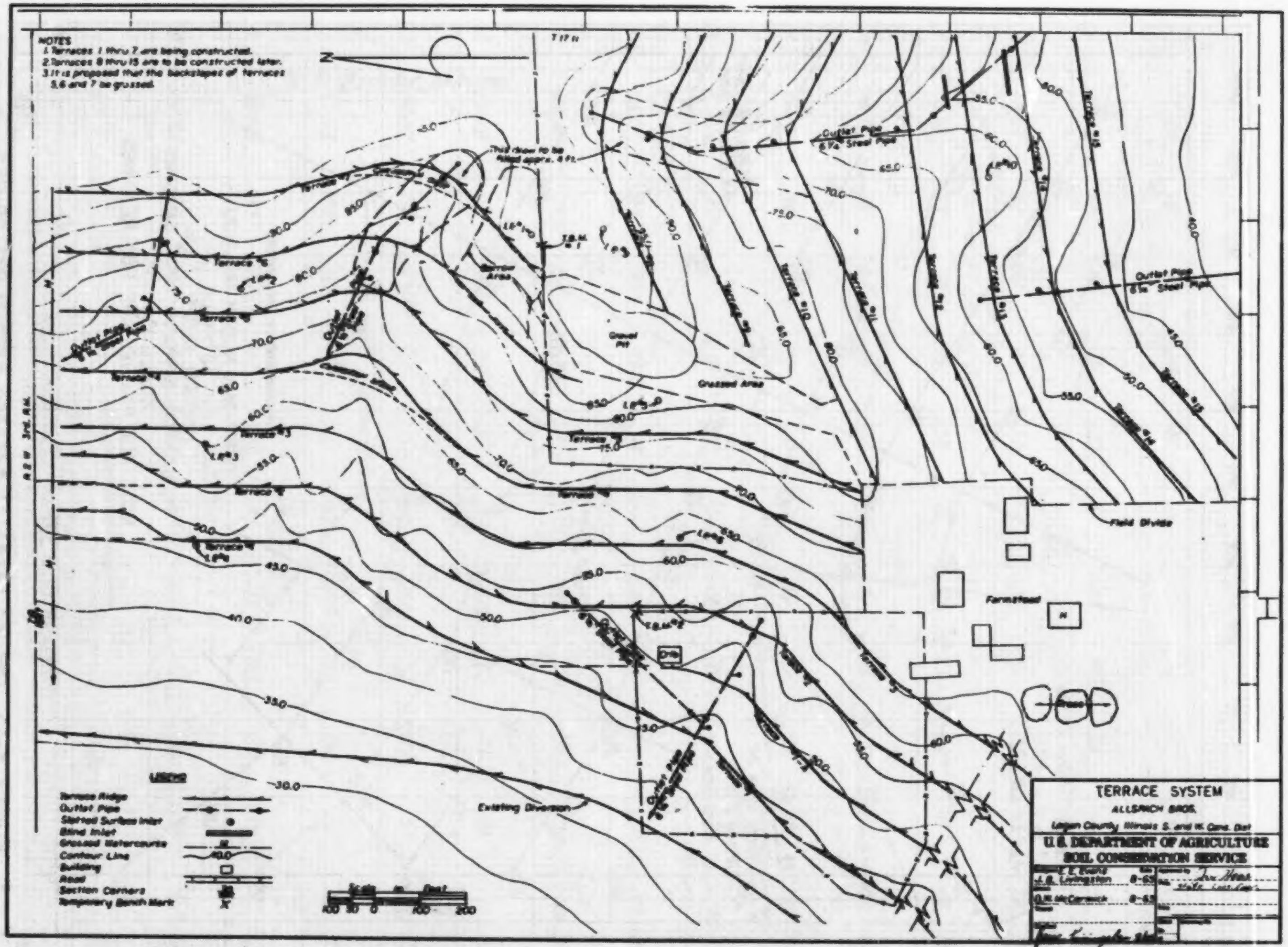

NOTES
1. Terraces 1 thru 7 are being constructed.
2. Terraces 8 thru 15 are to be constructed later.
3. It is proposed that the backslopes of terraces 5, 6 and 7 be grassed.
N
T 17 N
R 2 W 3rd. P.M.
This draw to be filled approx. 6 ft.
Outlet Pipe 6 ¼" Steel Pipe
Terrace #1
Terrace #2
Terrace #3
Terrace #4
Terrace #5
Terrace #6
Terrace #7
Terrace #8
Terrace #9
Terrace #10
Terrace #11
Terrace #12
Terrace #13
Terrace #14
Terrace #15
T.B.M. #1
T.B.M. #2
Borrow Area
Gravel Pit
Grassed Area
Field Divide
Farmstead
Existing Diversion
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
80.0
85.0
90.0
LEGEND
Terrace Ridge
Outlet Pipe
Slotted Surface Inlet
Blind Inlet
Grassed Watercourse
Contour Line
Building
Road
Section Corners
Temporary Bench Mark
Scale in Feet
100 50 0 100 200
TERRACE SYSTEM
ALLSPACH BROS.
Logan County Illinois S. and W. Cons. Dist.
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
J. G. Livingston 8-65
G. H. McCormack 8-65

Figure 8-45 Parallel terrace system using tile outlets developed from a topographic map

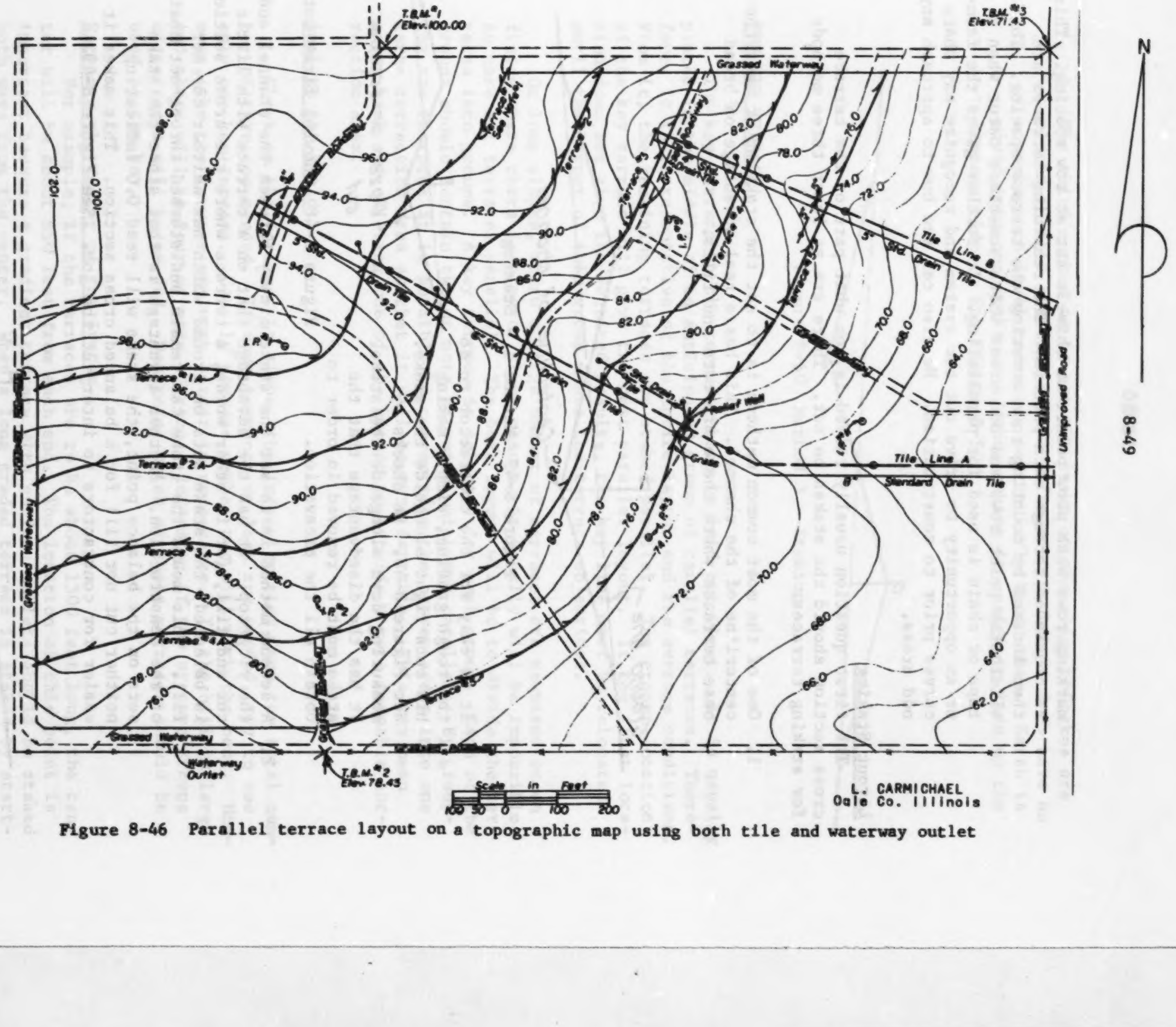

N
T.B.M. #1
Elev. 100.00
T.B.M. #3
Elev. 71.43
T.B.M. #2
Elev. 78.45
Grassed Waterway
Unimproved Road
Tile Line A
8" Standard Drain Tile
Tile Line B
5" Std. Drain Tile
3" Std. Drain Tile
6" Std. Drain Tile
Relief Well
Grass
Terrace #1
Terrace #2
Terrace #3
Terrace #4
Terrace #5
Terrace #1A
Terrace #2A
Terrace #3A
Terrace #4A
I.R. #1
I.R. #2
I.R. #3
I.R. #4
Waterway Outlet
102.0
100.0
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
82.0
80.0
78.0
76.0
74.0
72.0
70.0
68.0
66.0
64.0
62.0
Scale in Feet
100 50 0 100 200
L. CARMICHAEL
Ogle Co. Illinois

Figure 8-46 Parallel terrace layout on a topographic map using both tile and waterway outlet

marking rows with plow points or chisels set at row spacing. This is continued through each pattern. The remaining terraces are then located by counting rows covering the terrace spacing. This eliminates point rows and odd areas which sometimes occur when a tape or chain is used for paralleling. It further gives the farmer an opportunity to drive out the system and recognize any sharp curves prior to construction. He also can see how to approach any odd areas.

Layout Staking

The first question usually raised is, on what part of the terrace cross section should the stakes be set. There are at least three methods for staking terraces:

1. One of the most common methods is to set the stake at or near the centerline of the channel. This has a real advantage on broad base terraces where there are cuts and fills.

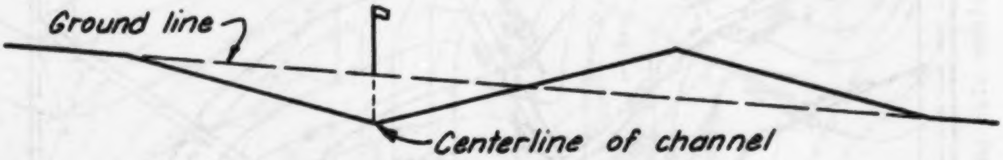


Figure 8-47 Method 1 - Staking

It is easy for the contractor to do the rough grading, simply making his cuts right alongside the stake. See Figure 8-48. He checks by measuring down alongside the stake. It has the disadvantage that the stake must be removed in order to obtain all the excavation.

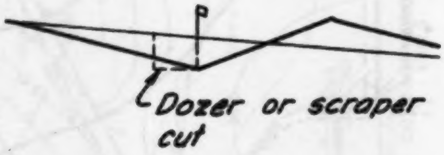


Figure 8-48 Showing first cut

2. A second method is to set the stake midway between the channel and the ridgetop. It has the advantage that on a terrace with little cut and fill, (or in other words, a terrace where the cross section is balanced) the stake sets on ground which has neither cut nor fill. This means the stake can remain undisturbed throughout most of the construction. Another advantage is that since the stake sets on the balance point, the stake will read 0.0 indicating neither cut nor fill for a balanced cross section. This makes it easier for contractors to interpret the job. See Figure 8-49.

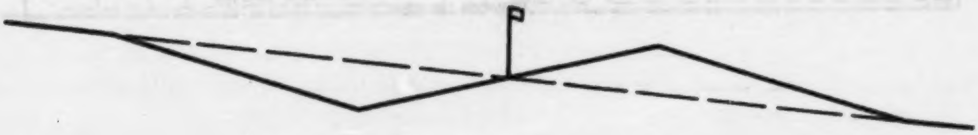


Figure 8-49 Method 2 - Staking

3. The third method is to set the stake on the ridge. Stakes are placed in this position rather infrequently, but it does have an advantage on level terraces, particularly broad base. Earth is moved into the stake line, thus making it easier to line up the terrace ridge. See Figure 8-50.

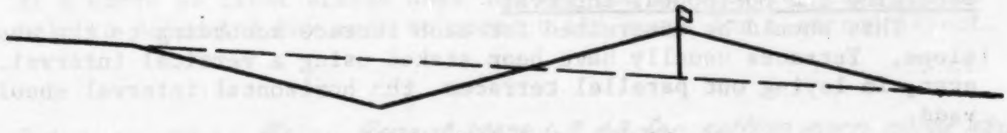


Figure 8-50 Method 3 - Staking

THE KEY TERRACE

The key terrace is the terrace which is laid out first. It is usually placed in the middle of an anticipated group of parallel terraces. Therefore, it is representative of the entire layout and the average conditions. From it, the remaining terraces are staked parallel. The proper location of the key terrace will give the best parallel layout. If the first location does not give the required results, the key line must be relocated until the layout of this group meets the terrace objectives.

On long slopes, where a large number of terraces are required or on fields where there is a major slope change, it usually will be impossible to make all terraces parallel. The best layout will be to divide the terraces into groups. A key terrace is selected for each group. Each of the groups should contain two or more terraces which are parallel. By grouping the terraces it is possible to concentrate the uneven areas into one large correction area so that it will be more farmable. This may mean going back and shifting one of the groups to provide a more farmable correction area.

Analyze the Field

Check on the variance in slope, the irregularities, and the total number of terraces needed. If four terraces or less are needed, try to use only one key terrace. Usually terrace number two will work the best. However, the top terrace may work better in some cases. If the hill is large and there will be four or more terraces, determine if two or more groups of terraces will be needed. Determine which of these terraces should be used as the key.

Estimate the Center of the System

For example, if the terraces are to be about 1300 feet long, the center will be about 650 feet from each end. The location of this point is important because a gradient terrace with surface outlets should be staked both ways from the center. When a long graded terrace is staked by starting at one end, the other end may be higher or lower than is wanted. Starting at the center generally will save time in layout and in adjusting the terrace location.

Locate the Top of the Hill or Slope

This should be the point from which the top terrace is located.

Determine the Average Land Slope

Determine the average slope for the area to be terraced. If the slope varies from one terrace to another, determine the slope for each terrace.

Determine the Horizontal Interval

This should be determined for each terrace according to the average slope. Terraces usually have been staked using a vertical interval. However, in laying out parallel terraces, the horizontal interval should be used.

Locate Center of Each Terrace Above Key Terrace

Measure down from the top of the hill toward the center of the system (if this is possible), using the determined horizontal interval to locate the approximate center of each terrace. Set one temporary stake on each of the lines above the key terrace and one on the key terrace. This provides a good idea as to the approximate location of the key terrace and the terraces above it.

It is best to use two different colors of stakes in locating the key terrace. If the key line is staked with white flags, red flags could be used for the adjusted key. This gives a clear picture of the adjustments made. The remainder of the key terrace flags should be replaced with the same color as the adjusted portion. After the system is all staked the white flags should be removed.

Examine the Key and Then Adjust It

Move the stakes to eliminate some curves. Open the terrace at ridges if needed to eliminate a sharp curve. Eliminate reverse curves if at all possible, especially where they are close together or of sharp curvature. Where the line is almost straight for long reaches, or curves slightly back and forth from a straight line, try to restake as a straight line. On tile outlet terraces adjust from a level line by raising the line on ridges and lowering it at depressions to give the desired grade in the channel toward the tile outlet. See Figure 8-51.

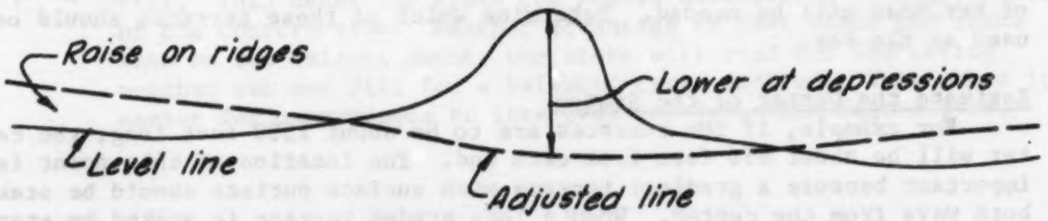


Figure 8-51 Adjustment of line crossing depressions

Use the Step Offset Method for Staking the Curves

This simple method is used to measure the amount of curvature of the line. It gives the technician a way he alone can lay out uniform curves and check the distance from the curve to its center. Thus, he can estimate how far on the inside of the curve rows can be planted before they become too sharp.

If a curve as first staked does not lay out as desired, this method will help to determine how much to correct the curve for a second layout.

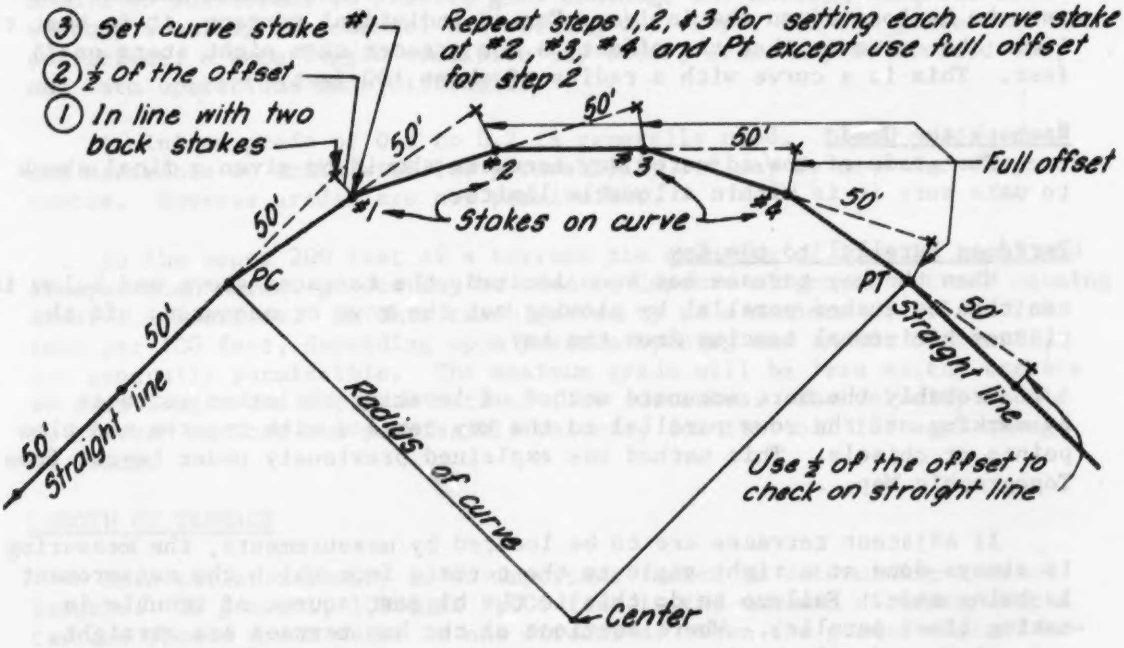

③ Set curve stake #1
② ½ of the offset
① In line with two back stakes
Repeat steps 1, 2, & 3 for setting each curve stake at #2, #3, #4 and Pt except use full offset for step 2
50'
50'
50'
50'
50'
50'
50'
50'
#1
#2
#3
#4
Full offset
Stakes on curve
PC
PT
Straight line
Straight line
Radius of curve
Center
Use ½ of the offset to check on straight line

Figure 8-52 Step offset method for staking a curve

As shown in Figure 8-52, the technician first starts with a stake where a straight section ends and the curve begins (P.C.). He paces off the distance ahead to the next stake, usually 50 feet. He looks backward and lines in with the straight line. To offset the stake, he paces sideways one-half the selected offset distance and sets curve stake No. 1. He repeats this process for the remaining curve stakes and the P.T. stake, except that he now uses the full offset at each stake. Usually curves will run from one-to three-step offsets. If the selected offset is too large or too small to fit the curve to the P.T. another offset is selected and the curve restaked.

The formula for determining the distance to the center (radius) of a curve requires only the offset distance at each 50-foot station.

$$\text{Radius (in feet)} = \frac{2500}{\text{offset in feet}}$$

For example, if a three-step offset curve has been staked, the offset at each station is nine feet, using a 3-foot step. Then:

$$\text{Radius} = \frac{2500}{9} = 280 \text{ feet (approximately)}$$

If rows are planted on the inside of the curve, somewhere around 230 feet inside the staked curve they will become too sharp to farm. This assumes that equipment could work on a curve with a 50-foot radius.

It is best when staking the key terrace to limit the curve offset to five or six steps (15 to 18 feet). This should still permit another terrace to be located on the inside. For an individual terrace, it is best to limit the curve so that the offset is not greater than eight steps or 25 feet. This is a curve with a radius of about 100 feet.

Recheck the Grade

The grade of the adjusted key terraces should be given a final check to make sure it is within allowable limits.

Terraces Parallel to the Key

When the key terrace has been located, the terraces above and below it can then be staked parallel by plowing out the rows or measuring off the planned horizontal spacing from the key.

Probably the more accurate method of locating the other terraces is by marking off the rows parallel to the key terrace with tractor and plow points or chisels. This method was explained previously under Layout from Topographic Map.

If adjacent terraces are to be located by measurements, the measuring is always done at a right angle to the terrace from which the measurement is being made. Failure to do this is the biggest source of trouble in making lines parallel. Where sections of the key terrace are straight, measuring need only be done at the ends of the straight sections. Intermediate stakes can be sighted in. On curves, measure from the key line to the adjacent terrace at 50-foot intervals. Refer to the discussion on Curves and Straight Lines in the section on Layout Geometry for locating and determining the beginning and end of the curves.

The grade of each terrace must be checked after the terraces have been staked. If the grades are out of tolerance, determine if cut and fill along the lines will permit the lines to remain where they are. Generally, a reasonable amount of cut and fill will allow the terraces to remain. If not, the key terrace should be changed, or perhaps another terrace selected for the key.

Use all the techniques shown under Alignment to make the lines parallel. If these do not give the relief needed, corrections areas will need to be planned. It may even be necessary to make further adjustment in terrace alignment in order to provide farmable correction areas.

11. DESIGN

The next step after the terrace system layout has been planned is to design the terraces and outlets. The design will depend on the type of outlet - surface or underground outlet - and the methods used for paralleling or providing the best possible alignment.

TERRACE GRADE

In determining grades for terraces, due consideration should be given to such factors as soil type, spacing, and length of terrace. Grades should be sufficient to provide good drainage and develop adequate flow without scouring the channel and washing out crops. If the grades are not sufficient, a waterlogged condition may occur, crops may be drowned out, and farm operations made difficult.

A minimum grade of 0.1 to 0.2 is generally used. Level grades are not desirable on soils with low permeability but may be used for short distances. Reverse grades are not permissible.

In the upper 200 feet of a terrace the quantity of flow is small and steeper than normal grades may be used to improve alignment without causing erosive velocities. In this reach grades up to a maximum of 1.5 to 2.0 feet per 100 feet, depending upon terrace spacing and amount of runoff, are generally permissible. The maximum grade will be less as the terrace becomes longer and the peak rate of flow increases. The velocity should be checked against the permissible velocity for the soil for each change of grade.

LENGTH OF TERRACE

Safe outlet capacity is an important factor in determining terrace lengths. In general, 1,800 to 2,000 feet is the maximum distance that a terrace should drain water in one direction. When the graded channel exceeds this length the terrace height becomes greater and this increases the earthmoving costs. When properly constructed and maintained, one-half mile long terraces will give satisfactory service on permeable soils, provided slopes are reasonably uniform. On badly gullied land a length of 1,200 feet should seldom be exceeded.

For tile outlet terraces it is a good practice to limit the length to about 1,200 feet per inlet.

WATERWAY OUTLETS

Waterway outlets must convey runoff from the terrace or terrace system, at a safe velocity, to a point where it can be discharged without erosion damage. Terrace outlets should be installed before terrace construction, when needed to insure the establishment of a good vegetative cover in the outlet channel.

If the field to be terraced receives any appreciable amount of runoff from an adjacent area, plans must be considered to divert the runoff from the terrace system by some form of diversion or interception ditch.

Refer to Chapter 7, Grassed Waterways and Outlets, for the design of vegetated terrace outlets.

CUT-AND-FILL METHOD

The major problem in the design of terraces which are to be built by the cut-and-fill method is to establish the gradeline of the channel and the ridge which will cause the earthwork to balance over the entire length of the terrace.

The following is a step-by-step procedure which can be used for design and layout. This procedure uses rod readings rather than elevations for stakes set in the terrace channel.

Survey the Terrace Line

After the terrace line has been established, take a rod reading at each stake, usually set every 50 feet. Enter these rod readings in the field notebook as shown in Figure 8-54. Convert all rod readings to the same HI if there is more than one instrument set up for a design segment.

Analyze the Rod Readings

Determine where the outlet will be on graded terraces. Determine the high points (lowest value of rod readings) where water will divide. These points are normally dividing points and terrace design and earthwork balance usually will be calculated between these divides.

Determine the Average Rod Reading

For the section being designed, add the rod readings and divide by the total number of readings. If stakes are set every 50 feet, each intermediate stake represents 50 feet of line. However, end stakes may only represent 25 feet. If this is true, add one-half of the sum of the two end readings to the sum of the intervening readings and divide the total by the number of rod readings minus one. This equals 9.5 for the example in Figure 8-54.

The average rod reading means that if the land lengthwise of the stake line was all graded level, the rod reading all along the line would be the average rod reading.

Locate the Balance or Midpoint

This will be the center of the design length. If the design length is 600 feet, the balance point will be at the 300-foot point. Note in Figure 8-53 that the center point does not change elevation as the line is tipped. The average rod reading will be at the center point, hence if the line is tipped either way the average rod reading does not change. Now if a plane is passed through this balance point at an elevation equal to the average rod reading the volume of excavation will equal the volume of fill regardless of how the plane is tipped.

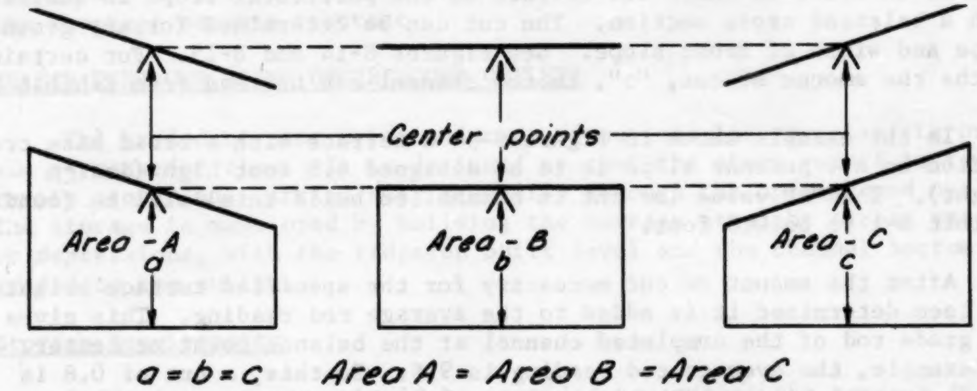
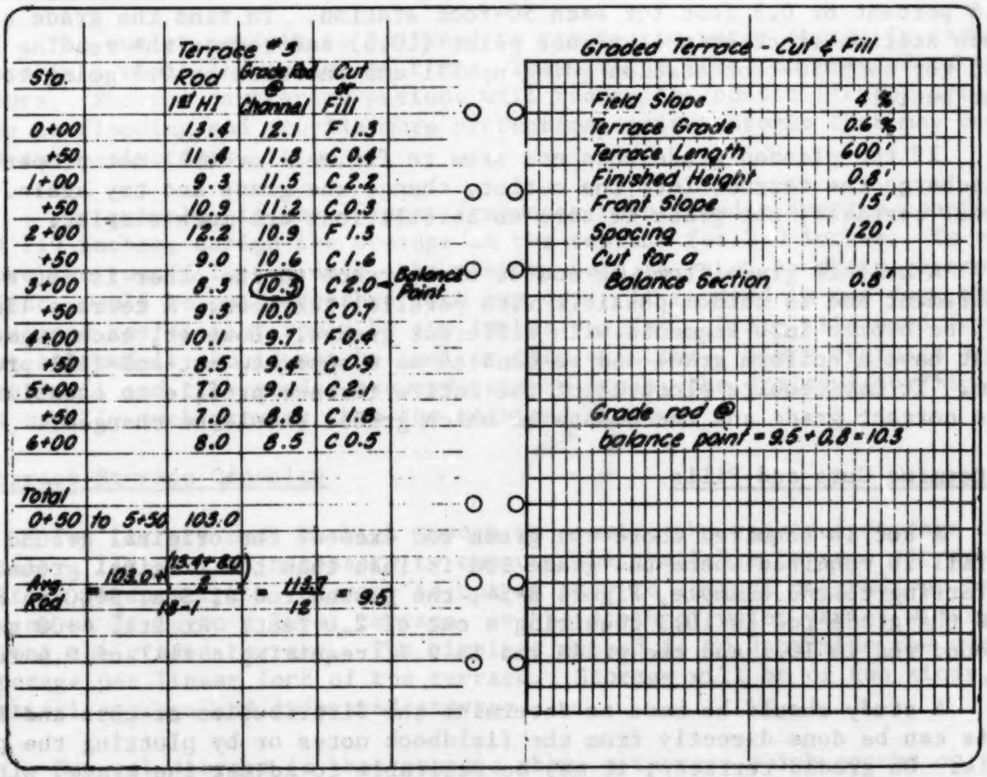


Figure 8-53 Theory of the balance point

The above figures were drawn of equal height below the balance point or center. They all contain the same area and represent the theory behind the balance point.



		Terrace #3			
Sta.		Rod 1st HI	Grade Rod @ Channel	Cut or Fill	
0+00		13.4	12.1	F 1.3	
+50		11.4	11.8	C 0.4	
1+00		9.3	11.5	C 2.2	
+50		10.9	11.2	C 0.3	
2+00		12.2	10.9	F 1.3	
+50		9.0	10.6	C 1.6	
3+00		8.3	10.3	C 2.0	← Balance Point
+50		9.3	10.0	C 0.7	
4+00		10.1	9.7	F 0.4	
+50		8.5	9.4	C 0.9	
5+00		7.0	9.1	C 2.1	
+50		7.0	8.8	C 1.8	
6+00		8.0	8.5	C 0.5	
Total					
0+50	to 5+50	103.0			

$$\text{Avg. Rod} = \frac{103.0 + \left(\frac{13.4+8.0}{2}\right)}{13-1} = \frac{113.7}{12} = 9.5$$

Graded Terrace - Cut & Fill

Field Slope	4 %
Terrace Grade	0.6 %
Terrace Length	600'
Finished Height	0.8'
Front Slope	15'
Spacing	120'
Cut for a Balance Section	0.8'

Grade rod @
balance point = 9.5 + 0.8 = 10.3

Figure 8-54 Graded terrace cut-and-fill notes

Determine Grade Rod of the Channel at the Balance Point

First, determine the amount of cut which will be necessary in the channel in order to build the terrace on the particular slope in question with a balanced cross section. The cut can be determined for any ground slope and width of front slope. See Figures 8-14 and 8-15. For certain depths the amount of cut, "c", in the channel can be read from Exhibit 8-1.

In the example shown in Figure 8-54 a terrace with a broad base cross section on a 4-percent slope is to be designed 0.8 foot high (design height). The "c" value (or cut in channel to build this) will be found in Exhibit 8-1 to be 0.8 foot.

After the amount of cut necessary for the specified terrace height has been determined it is added to the average rod reading. This gives the grade rod of the completed channel at the balance point or center. In our example, the average rod reading is 9.5. To this, a cut of 0.8 is added giving a grade rod reading at the balance point of 10.3.

Establish the Channel Grade

Proceed from the center point both ways with a planned grade. In the example, Figure 8-54, the channel grade rod is 10.3. The terrace grade is 0.6 percent or 0.3 foot for each 50-foot station. To find the grade at each station start at the balance point (10.3) and reduce the reading by 0.3 for each 50-foot station going uphill and increase by 0.3 going toward the outlet.

If the planned grade does not seem to fit well or will not properly discharge the terrace into the outlet, change the grade and try again. On level terraces, the grade is zero so calculations are much simpler.

A uniform grade from one end of the terrace to the other is not a requirement and is seldom possible with parallel terraces. A terrace line may be broken into segments with different grades. However, each segment must have a uniform grade and be handled as a separate cut-and-fill problem. It may require plotting of the entire terrace profile to establish the correct grade and the points at which grades should be changed.

Determine Cuts and Fills

A cut is required where the grade rod exceeds the original ground rod. A fill is required where the grade rod is less than the original ground rod. Referring to the example, Figure 8-54, the ground rod at Sta. 3+00 is 8.3 and the grade rod is 10.3 requiring a cut of 2.0 feet. At Sta. 4+00 the ground rod is 10.1 and the grade rod is 9.7, requiring a fill of 0.4 foot.

A study should be made to determine the distribution of cuts and fills. This can be done directly from the fieldbook notes or by plotting the profile. On graded terraces, it may be desirable to adjust the grade, within safe velocity limits, to prevent excessive earth haul from one end of the field to the other. Grades can be increased or decreased as dictated by the overall fall from one end of the terrace to the other.

The earth to complete the terrace may run long or short. Shortage of earth to make the fills is more desirable since it can be remedied by merely lowering the gradeline of the terrace channel by one or two tenths. This could be done during construction by the technician or contractor as the shortage becomes apparent.

GRADED TERRACES USING UNDERGROUND OUTLETS

The graded terrace using underground outlets incorporates the principle of retarded flow. It is designed so that the storm runoff is temporarily stored and carried away gradually through the underground outlet. The storage is developed by building the terrace straight across waterways or depressions, with the ridgetop built level and the channel bottom graded to the outlet.

Storage Requirements

Sufficient storage should be provided to protect the terrace from overtopping. The amount of storage required is generally based on a 10 year frequency storm. A minimum capacity of 2.0 inches of runoff is often used.

Drainage Coefficient

The outlet conduit is designed to remove the water stored in each terrace in a specified period of time. The maximum time recommended is 48 hours. Shorter dewatering periods will reduce the possibility of crop loss due to flooding and provide more protection against storms that may occur on successive days.

For example, if the 10-year frequency runoff under average conditions is 1.9 inches, design the storage in the terrace for 2.0 inches. To remove the runoff in two days, the minimum release rate, or drainage coefficient, would be one watershed inch per day. If removed in one day, the drainage coefficient would be two inches per day. Drain tile used for the outlet conduit should not be smaller than 4 inches. Since drainage areas are small and tile grades are moderate to steep, the drainage coefficient is usually much greater than the required minimum.

Terrace Storage Capacity

The terrace must be high enough to provide the required storage capacity. It will be necessary to compute the available terrace storage with a given height. Storage is not as easy to compute on gradient terraces as it is on a level terrace, as the depth of water varies widely along the graded terrace. The simplest method is to determine the average storage per linear foot of the terrace. Storage will be of two kinds, natural storage and excavated storage.

Natural storage is that storage above a terrace which occurs on top of the natural ground and against the terrace. It would be the entire storage on a terrace if there were no uphill borrow.

Excavated storage is that created by uphill borrow. Many terraces have both natural and excavated storage as shown in Figure 8-55.

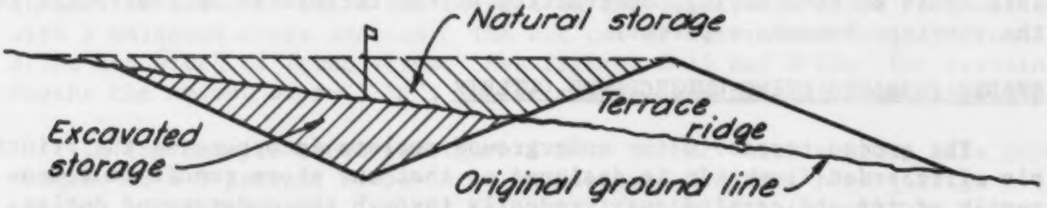
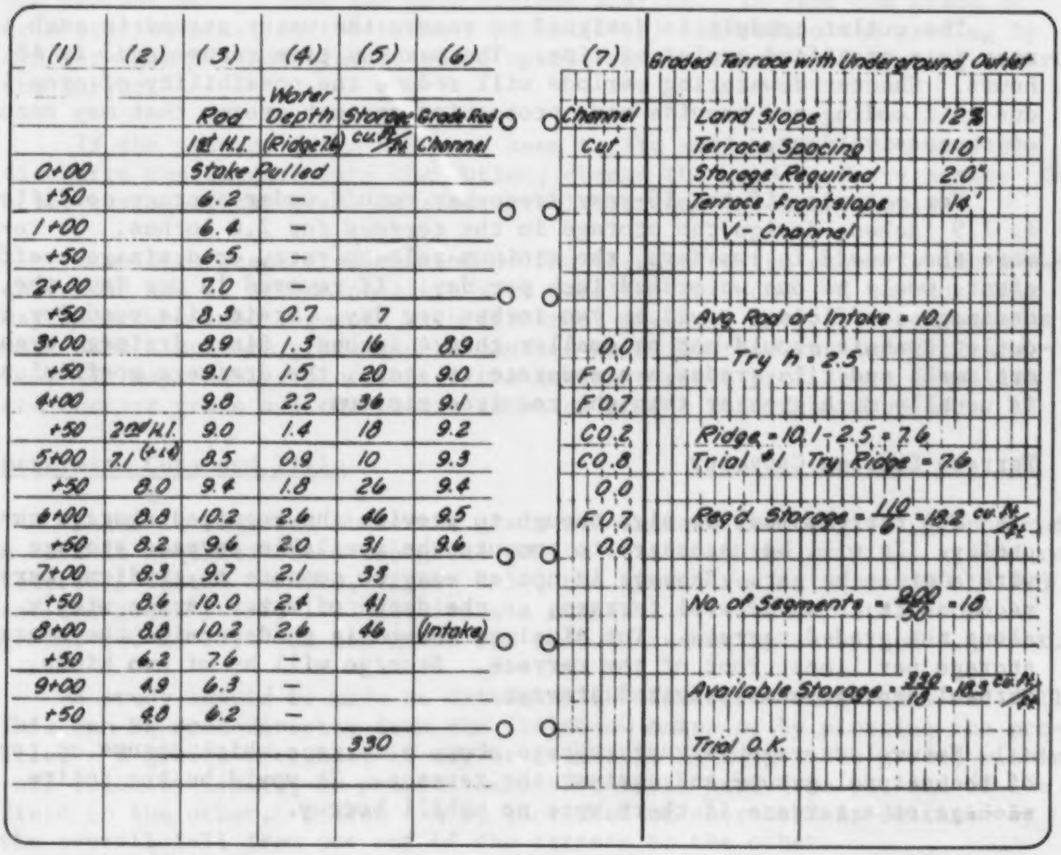


Figure 8-55 Storage - Natural and excavated

The following outlines procedures for determining the terrace height necessary to provide the required storage.

Natural Storage Design Procedure

In this example, the terrace will have a grass back slope cross section with the excavation all from the downhill side. Thus, all the storage will be natural storage. Refer to Figure 8-56 for field notes and calculations for the example.



(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Rod 1st H.I.	Water Depth (Ridge 7.6)	Storage cu.ft./ft.	Grade Rod Channel	Channel Cut
0+00		Stake Pulled				
+50		6.2	–			
1+00		6.4	–			
+50		6.5	–			
2+00		7.0	–			
+50		8.3	0.7	7		
3+00		8.9	1.3	16	8.9	0.0
+50		9.1	1.5	20	9.0	F 0.1
4+00		9.8	2.2	36	9.1	F 0.7
+50	2nd H.I.	9.0	1.4	18	9.2	C 0.2
5+00	7.1 (+1.4)	8.5	0.9	10	9.3	C 0.8
+50	8.0	9.4	1.8	26	9.4	0.0
6+00	8.8	10.2	2.6	46	9.5	F 0.7
+50	8.2	9.6	2.0	31	9.6	0.0
7+00	8.3	9.7	2.1	33		
+50	8.6	10.0	2.4	41		
8+00	8.8	10.2	2.6	46	(Intake)	
+50	6.2	7.6	–			
9+00	4.9	6.3	–			
+50	4.8	6.2	–			
				330		

Graded Terrace with Underground Outlet

Land Slope	12%
Terrace Spacing	110'
Storage Required	2.0"
Terrace frontslope	14'

V - Channel

Avg. Rod of Intake = 10.1

Try h = 2.5

Ridge = 10.1 - 2.5 = 7.6

Trial #1 Try Ridge = 7.6

Req'd Storage = $\frac{110}{6}$ = 18.2 cu.ft./ft.

No. of Segments = $\frac{900}{50}$ = 18

Available Storage = $\frac{330}{18}$ = 18.3 cu.ft./ft.

Trial O.K.

Figure 8-56 Notes - Graded terrace with underground outlet

1. Enter the rod readings for each 50-foot stake set in the channel along the terrace.

2. Convert all rod readings to the same HI if there is more than one instrument setup. However, this needs to be done only for a particular design section. Note that the instrument was moved, with Sta. 5+00 used for a turn. The foresight on 5+00 was 8.5 and the backsight was 7.1. Enter readings from first HI in the third column, those from the second HI in the second column. In the example, readings from the second HI were converted and placed in the third column by adding 1.4 to each.

3. Plot and analyze the rod readings. Determine where the underground outlet will be. In the example, the outlet should be at Sta. 8+00 which is the low point. See Figure 8-57 for plotted profile. Determine the high points where water will divide to establish the design length. In the example, this is from Sta. 0+50 to 9+50 = 900 feet.

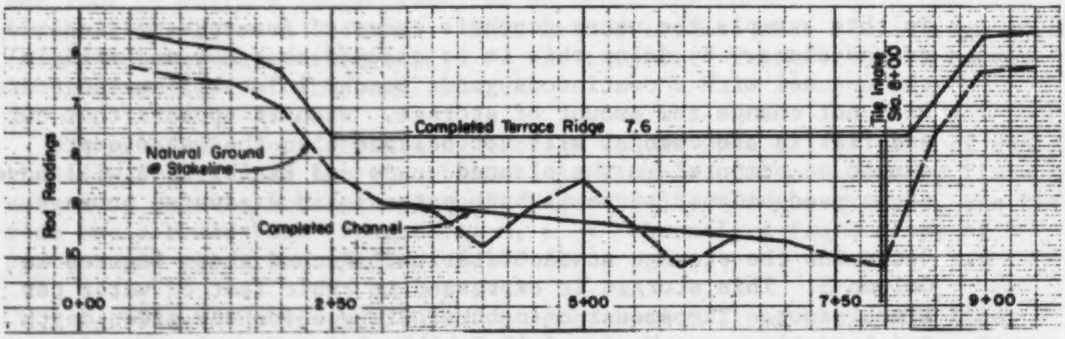


Figure 8-57 Profile of terrace (Borrow was obtained from ridges to complete the fill section)

4. Establish a proposed top or ridge height for the storage section of the terrace. Plot this estimated elevation or grade rod on the terrace profile as shown in Figure 8-56.

The readings at the ends of the terrace that are much higher than the assumed level ridge top should be eliminated from the storage calculations. In this example, the first four readings and the last three readings were not used since these parts of the terrace will be built only as a graded terrace.

Locating the required ridge height is a cut-and-try process. Experience in the design of this type of terrace provides the best judgment in locating the ridge height. The following guides are based on past designs and may be used as a starting point.

Percent of the length of terrace over which water will be stored	Estimated maximum design height measured at the average low point at the intake
Approx. 75 percent of length	2.0 feet
Approx. 50 percent of length	3.0 feet
Approx. 25 percent of length	4.0 feet

These guides work best on slopes of 3 to 6 percent and for a design length of terrace of 1,000 feet or less. For terraces over 1,000 feet, add additional height as the design section becomes longer.

In the example 10.1 was considered average rod near the intake. The storage portion is + 60 percent of terrace length so 2.5 was used for the maximum design height. Grade rod at ridge = 10.1 - 2.5 = 7.6.

5. Determine the water depths at each station and record in Column 4, Figure 8-56. For example, at Sta. 4+00 the ground rod is 9.8, the proposed ridgetop is 7.6, and the water depth will be 9.8 - 7.6 = 2.2 feet.

   In this example the water depth is computed from the original ground shots. By doing this it is assumed that cut and fill in the channel with a continuous grade to the inlet will balance and will not change the amount of storage. When it appears that cut and fill in the channel will not balance then the water depth should be computed to the planned grade and Exhibit 8-3 will have to be used because there is both natural and excavated storage.

6. Determine the storage at each station. Record these figures in Column 5. This storage is expressed in cubic feet of water per lineal foot. The amount of natural storage for any given depth and land slope can be found in Exhibit 8-2. Example: At Sta. 4+00 for a depth of 2.2 feet and a 12-percent slope the storage amounts to 36 cu.ft./ft.

   Exhibit 8-2 is to be used where all, or the majority, of the excavation comes from other than in the terrace channel. This would be the case where terraces have grass back slopes and the excavation comes from the downhill side. It would also pertain to broad base terraces where fill for the terrace is carried in with a scraper from a distant source. All calculations are based on a stake line 14 feet uphill from the completed terrace ridge. Where fills are over 3 feet, front slope should be increased to 28 feet to give better farmability.

7. Determine the available storage. Add the storage volumes in Column 5 and divide by the number of 50-foot increments. This gives the average storage along the length of the terrace. Total storage from Col. 5 = 330 in the example. The number of increments are 900 feet of terrace + 50-foot stations = 18. The

average available storage prorated over the entire length of the terrace is then $\frac{330}{18} = 18.3$ cu.ft./ft.

8. Determine the required storage. Multiply the average width of the drainage area above the terrace by the storage required in feet. In the example, the average width of the drainage area above the terrace (terrace spacing) is 110 feet and 2 inches (1/6 of a foot) of storage are required, then 110 ft. x 1/6 ft. = 18.2 cu.ft./ft. This is slightly less than the storage available, therefore the height estimated in step 5 is satisfactory.

9. Recompute if necessary. If the storage is too low or too high, recompute the terrace with a different height.

Excavated Storage Design Procedure

Where all or part of the fill for the terrace comes from uphill borrow, storage will be increased due to the excavation. This increase in storage can be used to reduce the ridge height.

Storage calculations are based on the average storage in cubic feet per foot of terrace length required to store the runoff from a one-foot width of the terrace interval. This method assumes that the storage volume is spread over the entire length of the terrace. Therefore, all survey stations must be at the same interval.

A procedure for determining storage volume when all or part of the channel is excavated is shown below. An example of the necessary field notes and calculations are given in Figure 8-58. In the example, the terrace has a broad base cross section, a "V" channel, a field slope of 5 percent and a terrace spacing of 140 feet.

1. Enter the rod readings for each station along the stake line. This step is the same as for natural storage design. See Figure 8-58.

2. Plot a profile of the rod readings. Study the profile and locate the high points where water will divide. This determines the design length. Then locate the inlet. With the inlet elevation as the control, set the grade for the terrace channel and draw this on the profile as shown in Figure 8-59.

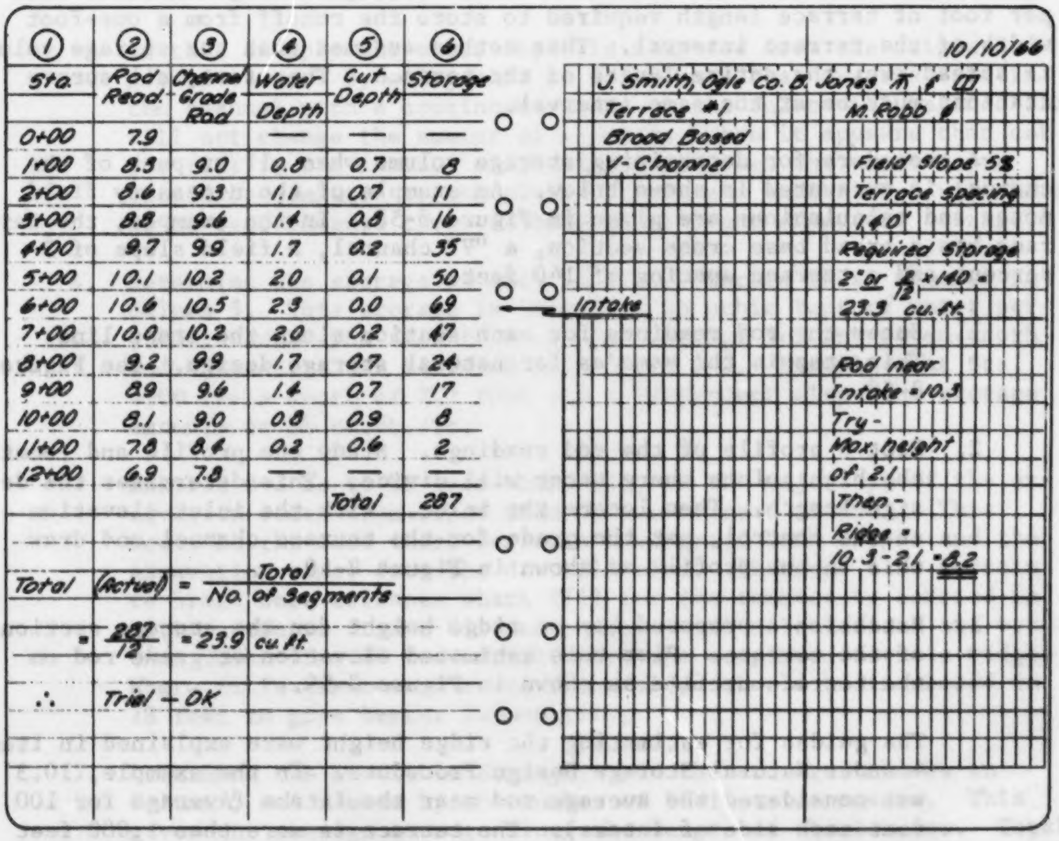
3. Establish a proposed top or ridge height for the storage section of the terrace. Plot this estimated elevation or grade rod on the terrace profile as shown in Figure 8-59.

   The guides for estimating the ridge height were explained in item 4 under Natural Storage Design Procedure. In the example, 10.3 was considered the average rod near the intake (Average for 100 feet each side of intake). The terrace is more than 1,000 feet long, and the storage section is more than 75 percent of the terrace length. Try a maximum height of 2.1. The grade rod at the ridge would be 10.3 - 2.1 = 8.2.

4. Determine the water depth at each station. This is the difference between the grade rod of the ridge and the proposed bottom of the terrace. In the example, at Sta. 5+00 the terrace bottom grade rod is 10.2. Subtract ridge grade rod of 8.2 giving the water depth of 2.0. Do this for each station and enter in Column 4, Figure 8-58.

5. Determine the cut depth at each station. This is the difference between the rod readings at the stake line and the proposed bottom of the terrace channel. At Sta. 5+00 with the bottom grade rod of 10.2 and the grade rod at the ground line of 10.1, a cut of 0.1 will be required. Do this for each station and enter in Column 5.

6. Determine the end area at each station. For the design depth shown in Column 4 and the cut depth shown in Column 5, select the end area from Exhibit 8-3. At Sta. 3+00, d = 1.4, C = 0.8. From Exhibit 8-3, sheet 5, for 5-percent field slope, the end area = 16 square feet. Enter this in Column 6.



①	②	③	④	⑤	⑥
Sta.	Rod Read.	Channel Grade Rod	Water Depth	Cut Depth	Storage
0+00	7.9		—	—	—
1+00	8.3	9.0	0.8	0.7	8
2+00	8.6	9.3	1.1	0.7	11
3+00	8.8	9.6	1.4	0.8	16
4+00	9.7	9.9	1.7	0.2	35
5+00	10.1	10.2	2.0	0.1	50
6+00	10.6	10.5	2.3	0.0	69
7+00	10.0	10.2	2.0	0.2	47
8+00	9.2	9.9	1.7	0.7	24
9+00	8.9	9.6	1.4	0.7	17
10+00	8.1	9.0	0.8	0.9	8
11+00	7.8	8.4	0.2	0.6	2
12+00	6.9	7.8	—	—	—
				Total	287

Total (Actual) = $\frac{\text{Total}}{\text{No. of Segments}}$

$= \frac{287}{12} = 23.9$ cu. ft.

∴ Trial – OK

10/10/66

J. Smith, Ogle Co. B. Jones

Terrace #1

M. Robb

Broad Based

V-Channel

Field Slope 5%

Terrace spacing

140'

Required Storage

2" or $\frac{2}{12} \times 140 =$

23.3 cu. ft.

Intake

Rod near

Intake = 10.3

Try -

Max. height

of 2.1

Then -

Ridge =

10.3 - 2.1 = 8.2

Figure 8-58 Notes - Graded terrace with underground outlet - broad base cross section

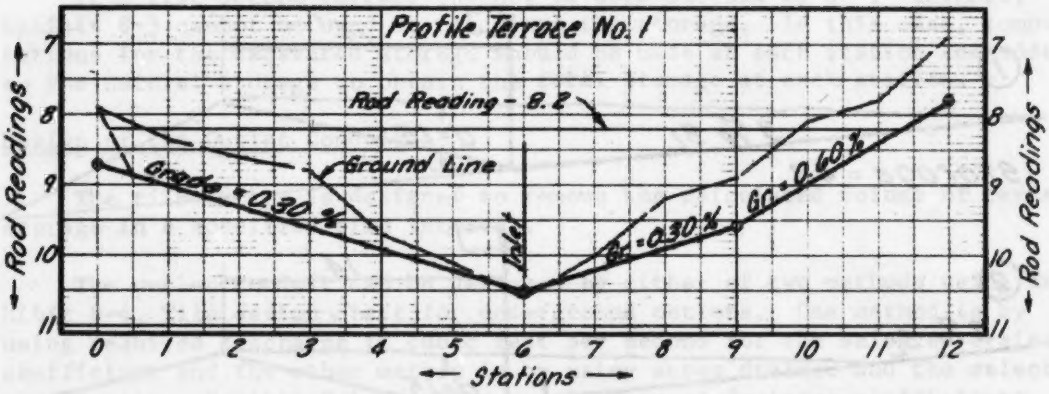


Figure 8-59 Profile for terrace design example

Exhibit 8-3 has been developed to aid in computing combined natural and excavated storage. The exhibit can be used where the storage is all natural (c = 0.0); where the storage is a combination of natural and excavated; and where the storage is all excavated. See Figure 8-60. In using this exhibit, first determine the land slope at each station and refer to the exhibit for that land slope. The storage figures in the exhibit are cubic feet per lineal foot of terrace (end area in square feet times a unit length of one foot). The exhibit has been carried only to a "d" of 3 feet. It will be rare if there is excavation in the channel of depths over this amount. For natural storage on depths over 3 feet use Exhibit 8-2, Natural storage above terraces.

This exhibit is based on a "V" channel cross section with a 14-foot front slope and an excavated cut slope of 6:1. The stake line in the "V" channel is 14 feet uphill from the completed terrace ridge. The terrace ridge is constructed to the design depth "d", even when "c" exceeds "d" (see drawing 4 in Figure 8-60). This means that the water surface at depth "d" always measures 14 feet from the stake line to the completed terrace ridge. Freeboard will have to be provided above the "d" level.

7. Determine the available storage. Total all of the end areas in Column 6. Divide this total by the number of survey stations in the design length of terrace to determine the storage in cubic feet per foot of length. The full length of the terrace must be used as the average end area must be applied to the full length, not just the storage portion of the profile. This is because the full length must be used in step 8 to determine the required storage based on the total runoff to the entire design length of terrace. In the example the available storage provided per foot of length is $\frac{287}{12} = 23.9$.

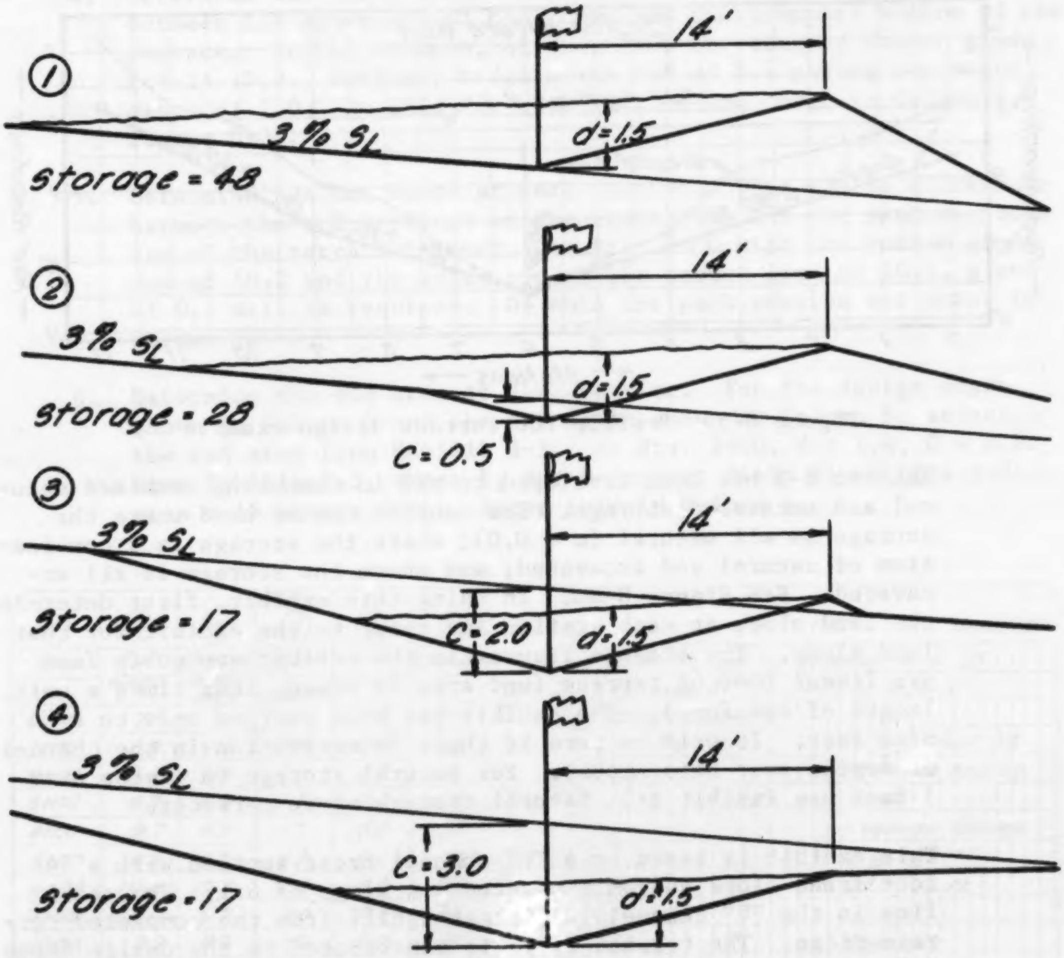


Figure 8-60 Examples of "c" and "d" situations for figuring storage

8. **Determine the required storage. Multiply the average width of the drainage area above the terrace by the depth of the runoff in feet. The required storage in this example is equal to $140 \times \frac{2}{12} = 23.3$ cubic feet per foot. As the available storage in the previous step is 23.9, the first trial meets requirements and the grade rod for the designed height of the terrace is 8.2. Additional height should be added to the terrace to allow for freeboard and settlement.**

If the available storage is less than the required storage, raise the terrace ridge and recompute the available storage. If the available storage in step 8 is significantly more than the required storage, lower the grade rod of the terrace and recompute the available storage. Seldom will more than two trials be required to determine the ridge height of a terrace of this type.

If a flat-bottom terrace channel is used instead of a "V" channel, Exhibit 8-3 cannot be used to calculate the storage. In this case, computations for the excavated storage should be made at each station and added to the natural storage to obtain the total storage at each station.

Design of the Outlet Conduit

The tile outlet is designed to remove the calculated volume of terrace storage in a specified time interval.

The outlet conduit can be designed by either of two methods using Exhibit 8-4, Tile design chart for underground outlets. One method is by using required discharge in cubic feet per second for the selected drainage coefficient and the other method is by using acres drained and the selected coefficient. Exhibit 8-4 provides a selection of drainage coefficients from 1/2 inch to 3 inches for both discharge in cubic feet per second and acres drained. Using drainage area in acres is the simplest and most common method.

The tile should be designed for open channel flow with velocities in accordance with National Engineering Handbook, Section 16, Chapter 5. The design procedure is to start with the top terrace and accumulate the drainage area or discharge rate of each terrace, moving downhill.

The following example illustrates this procedure using drainage areas:

Given - Slope of tile outlet through all terraces = 3.0 percent
Slope of tile outlet across bottom = 0.5 percent
Drainage coefficient = 2.0 in./day

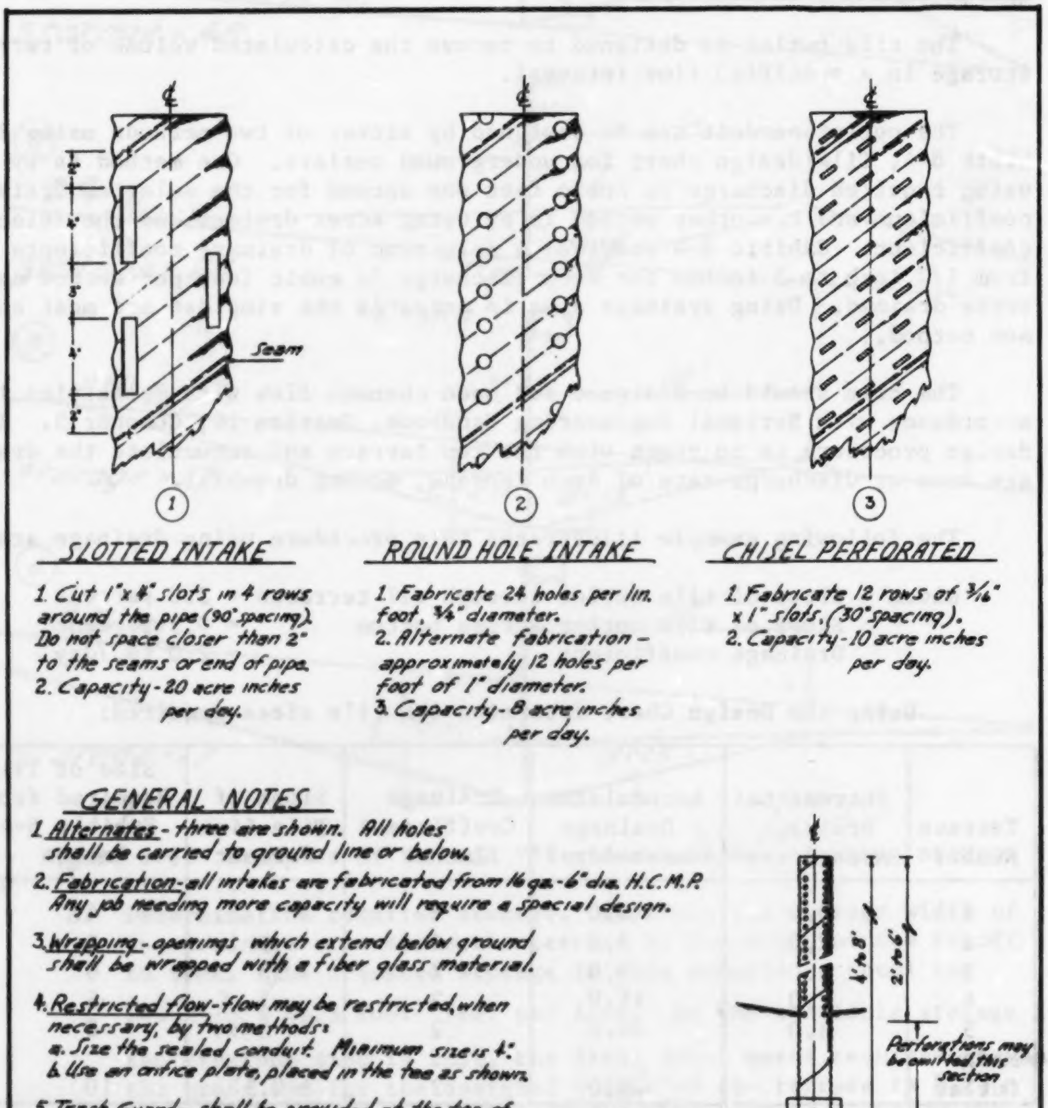
Using the Design Chart determine the tile sizes required:

Terrace Number	Incremental Drainage Area-Acres	Accumulated Drainage Area-Acres	Drainage Coefficient Inches	Slope of Tile Line Percent	Size of Tile Required from Exhibit 8-4 Inches
1	4.0	4.0	2	3	4
2	2.0	6.0	2	3	5
3	3.0	9.0	2	3	6
4	2.0	11.0	2	3	6
5	3.0	14.0	2	3	8
Main Outlet		14.0	2	0.5	10

Intake or Riser

The intake extends above the ground and directs the flow into the underground outlet. Intakes generally are placed on a lateral leading to the main line. The lateral should be of sealed conduit. The intake should be of sturdy construction and securely connected to the lateral conduit. The intake should extend almost up to the elevation of the terrace top. This gives a higher factor of safety against plugging by trash.

It also permits sediment to build up gradually over the years without having to raise the intake. For this reason the beehive grating is not recommended.


℄
2"
4"
3"
4"
2"
Seam
1
2
3
℄
4' to 8'
2' to 6'
Perforations may be omitted this section
Orifice-if needed.
Plug and with concrete.
10" or 12" Drain tile, fill with concrete to form a joint block.
Sealed Conduit
Use tee or elbow

SLOTTED INTAKE

1. Cut 1" x 4" slots in 4 rows around the pipe (90° spacing). Do not space closer than 2" to the seams or end of pipe.
2. Capacity - 20 acre inches per day.

ROUND HOLE INTAKE

1. Fabricate 24 holes per lin. foot, 3/4" diameter.
2. Alternate fabrication - approximately 12 holes per foot of 1" diameter.
3. Capacity - 8 acre inches per day.

CHISEL PERFORATED

1. Fabricate 12 rows of 3/16" x 1" slots, (30° spacing).
2. Capacity - 10 acre inches per day.

GENERAL NOTES

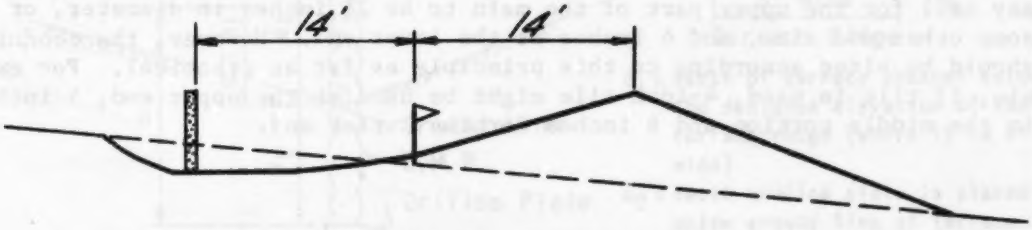
1. Alternates - three are shown. All holes shall be carried to ground line or below.
2. Fabrication - all intakes are fabricated from 16 ga. - 6" dia. H.C.M.P. Any job needing more capacity will require a special design.
3. Wrapping - openings which extend below ground shall be wrapped with a fiber glass material.
4. Restricted flow - flow may be restricted, when necessary, by two methods:
  a. Size the sealed conduit. Minimum size is 4".
  b. Use an orifice plate, placed in the tee as shown.
5. Trash Guard - shall be provided at the top of each intake. One type can be made by drilling holes and inserting two horizontal bars at a 2" spacing.

Figure 8-61 Types of opening for intakes of helical corrugated metal pipe

Helical corrugated metal pipe is generally used for the intake. Openings should be placed in it from the ground level to the top to permit flow to enter and still restrict floating grass, stalks, and other trash. Openings have been made of slots (1 x 3 inches), round holes (1/2 to 1 inch in diameter), and chisel perforations (usually 3/16 to 1 inch). The openings should be sufficiently numerous to pass the required flow even if some are obstructed. See Figure 8-61 for information on the three types of openings for intakes. Other types of intakes can be used that fulfill the above criteria.

The intake generally is placed at the lowest spot on the terrace profile in order to drain all the terrace channel. It should be placed uphill of the terrace ridge - a multiple of the planting and harvesting equipment widths - so that it will pass all equipment which will be used.

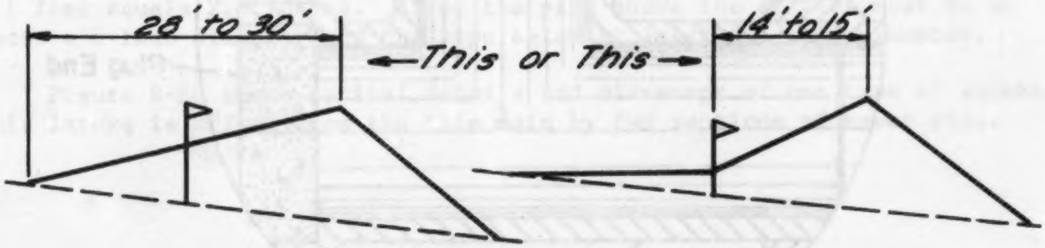
It may be necessary to either excavate around the intake, or fill in the channel, so that the intake is the lowest part of the completed terrace channel. See Figure 8-62. If the fill is rather high at the intake, the front slope will need to be lengthened to prevent it from becoming too steep.



On most fills (under 3') grade around the intake so the terrace channel will all drain to the intake.

Figure 8-62 Grading around intake

This also requires placing the intake farther away. As an alternate, the channel can be filled to lessen the height. This will permit placing the inlet closer to the ridge. See Figure 8-63.



Use a 28' to 30' frontslope on fills over 3 feet

Fill in channel to lessen the height to 3 feet and use a 14' to 15' frontslope

Figure 8-63 Front slope treatment for fills over 3 feet

To protect the intake from damage by equipment or livestock, it is best to leave a small area in sod around the intake. Crops should be planted out around the grassed area so that equipment will be led away from the intake. See Figure 8-81. A series of fence posts placed around the intake also will protect against livestock and equipment damage.

Preventing Pressure Flow in Outlet

If a large number of terraces are graded to an underground outlet, overtopping of the lower terraces may occur if the same conduit size is used throughout and the lower end of the conduit is on a much flatter grade than the upper end. Pressure flow may develop in the line and cause water to flow out of the lower intakes rather than into them. This might cause the lower terraces to overtop. There are several methods which can be used in design to prevent this.

Conduit Sizing

The main outlet conduit can be sized using approximately the same drainage coefficient for all terraces with the size of the line increasing as it proceeds downhill. This approach is not always practical as this may call for the upper part of the main to be 2½ inches in diameter, or some other odd size, and 4 inches at the lower end. However, the conduit should be sized according to this principle as far as practical. For example, if tile is used, 4-inch tile might be used at the upper end, 5 inches in the middle portion and 6 inches for the outlet end.

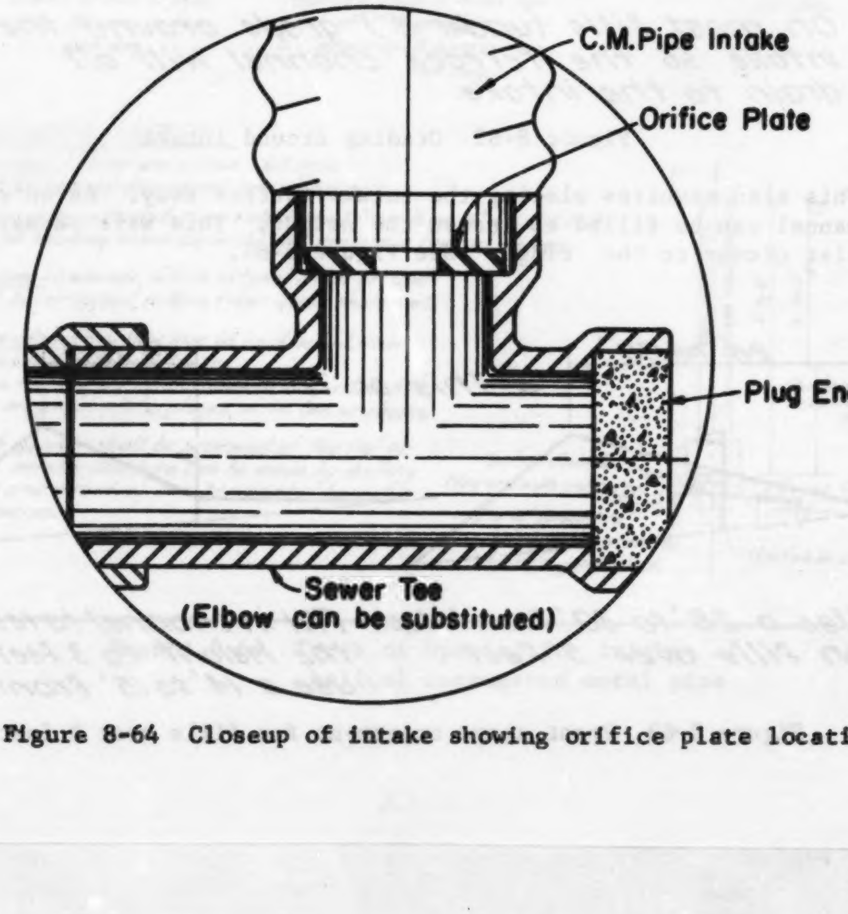
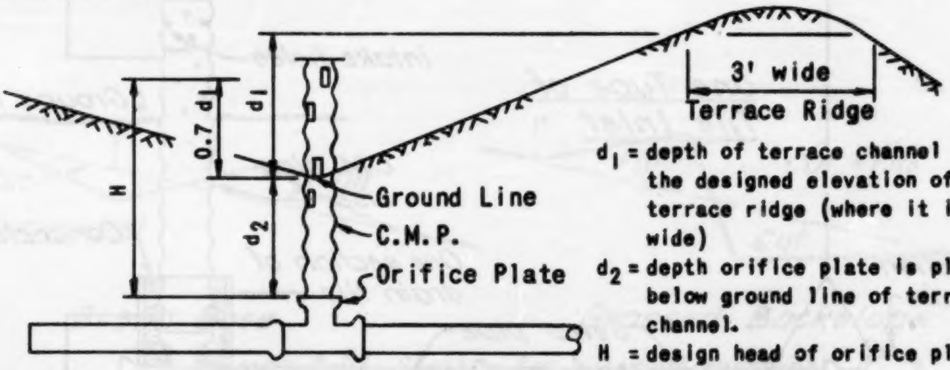


Figure 8-64 Closeup of intake showing orifice plate location

Restricting Device in the Intake

The flow may be restricted before it enters the main. This should not be done by reducing the size or number of holes in that portion of the intake above ground. The restriction should be placed in the intake below the ground level. One of the simplest devices is a flat metal orifice plate lowered into the intake from above and set on the shoulder of the bell of the sewer tile. Should it become plugged, it can be removed by using a rod with a hook on one end. See Figure 8-64.

When an orifice plate or some other type of restriction is used it will be necessary to determine the discharge in cubic feet per second for the drainage coefficient used, the drainage area of the inlet (Exhibit 8-4), and the head of the orifice. See Figure 8-65. With this information, the diameter of orifice and size of riser pipe can be determined from Exhibit 8-5.



d_1 = depth of terrace channel below the designed elevation of the terrace ridge (where it is 3' wide)

d_2 = depth orifice plate is placed below ground line of terrace channel.

H = design head of orifice plate.

$H = 0.7d_1 + d_2$

Figure 8-65 Design head for orifice plate

Example: Required discharge of .33 c.f.s. Height of terrace ridge = 3.0 feet. Orifice plate is 2.0 feet below channel bottom.

Head on orifice, $H = (0.7 \times 3) + 2 = 4.1$ feet. From Exhibit 8-5, find that the orifice diameter for a discharge of .33 c.f.s. at a head of 4.1 feet equals 2.5 inches. Also, the pipe above the orifice must be at least a 6-inch diameter and the pipe below at least a 4-inch diameter.

Figure 8-66 shows typical details and placement of one type of intake. This intake is offset from the tile main by two sections of sewer pipe.

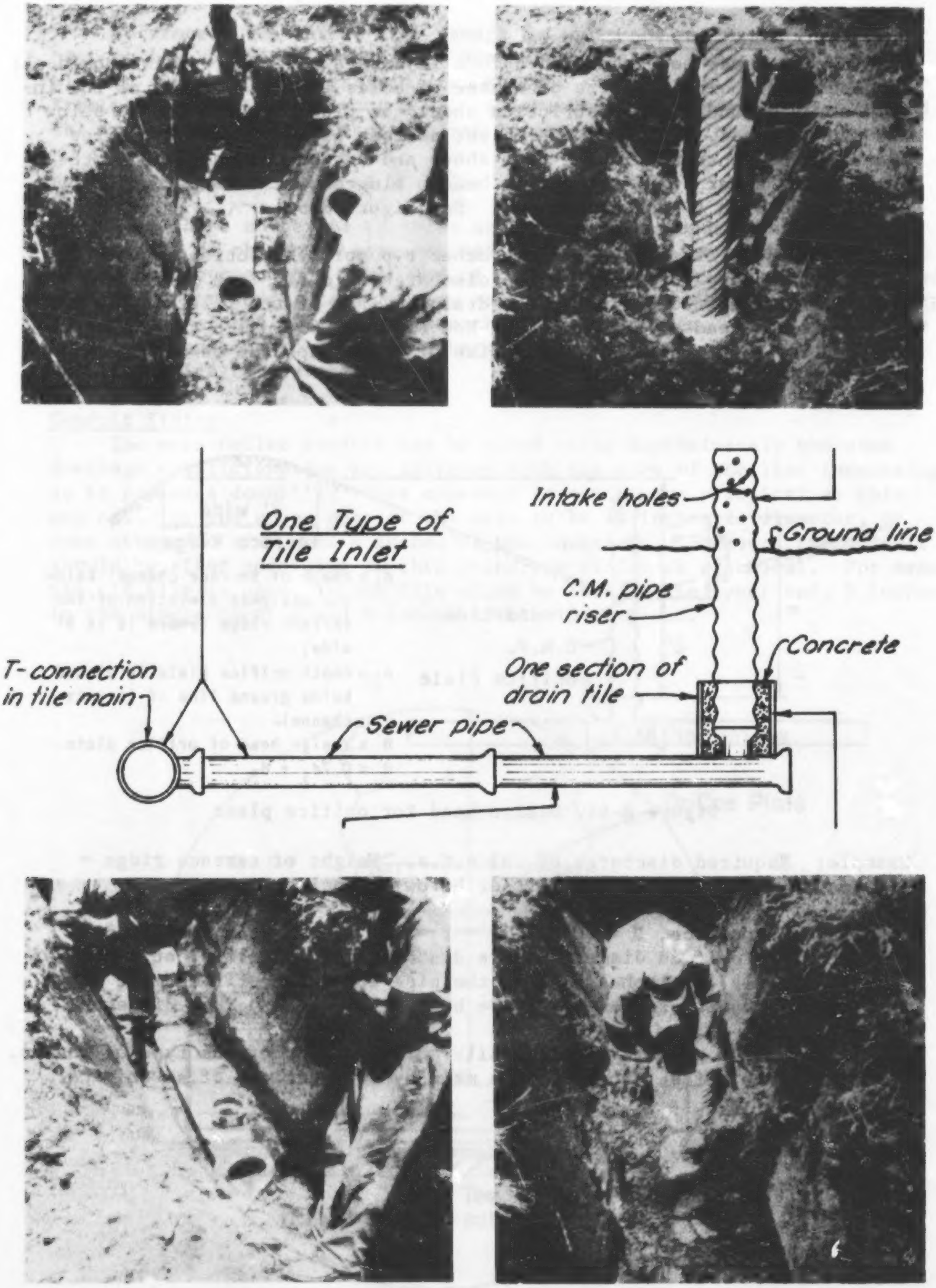

One Type of Tile Inlet
Intake holes
Ground line
C.M. pipe riser
Concrete
One section of drain tile
T-connection in tile main
Sewer pipe

Figure 8-66 Typical details and placement of intake

12. CONSTRUCTION

The best planned terrace system, if poorly built, may result in the farmer being dissatisfied. Some of the difficulties of construction can be avoided by proper staking and explanation of the plans and specifications with the contractor and landowner.

CONSTRUCTION STAKING

Terraces fall into two construction categories, those with a uniform or balanced cross section and those requiring cuts and fills.

Balanced Cross-Section Terraces

The balanced cross-section terrace is one in which all earth is moved laterally in the cross section and the borrow at each station equals the fill. Thus, each cross section is balanced as far as earthmoving is concerned.

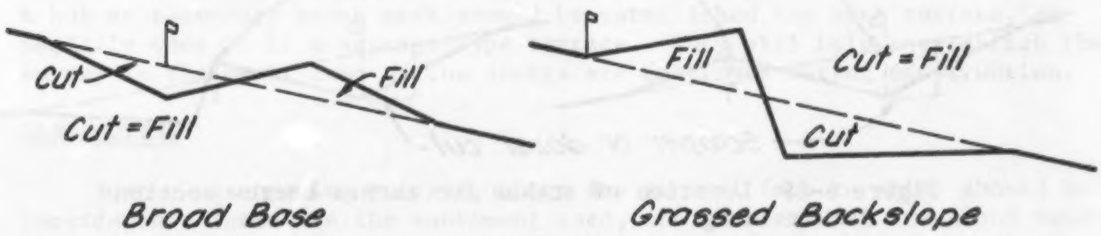


Figure 8-67 Staking for balanced sections

Generally, no construction stakes are needed for the balanced cross-section terrace other than the original layout stakes. See Figure 8-67. One exception is for a terrace with a grass back slope using borrow from below. Here it is advisable to mark with a plow or other tool the points along the terrace where the maximum cut occurs, which is the toe of the completed back slope. See Figure 8-68. This is especially important for new contractors.

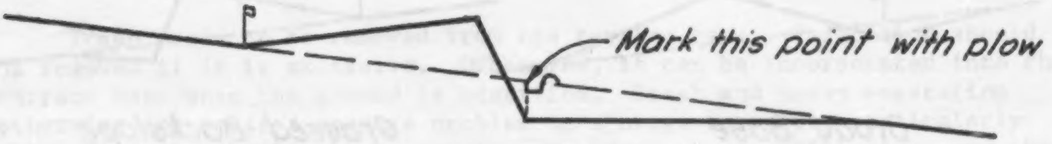


Figure 8-68 Marking toe of grass back slope

Cut-and-Fill Terraces

This terrace has cuts and fills along its length that require earth to be moved longitudinally as well as laterally. It will have three basic types of cross section within its length: the balanced section, the excess borrow section, and the excess fill section.

Balanced Section

For the balanced section only the layout stakes are normally required. However, since the balanced section occurs among nonbalanced sections, it will be necessary to stake the cut.

Excess Borrow Section

Where heavy cuts are required, the cut should be marked on the layout stake. A construction stake also may be required. Figure 8-69 shows cutting directly beside the layout stake for the uphill borrow. If the cut is so deep that no fill or very little fill is required for the ridge, a hub or blue top should be set on the ridge showing the required height of fill.

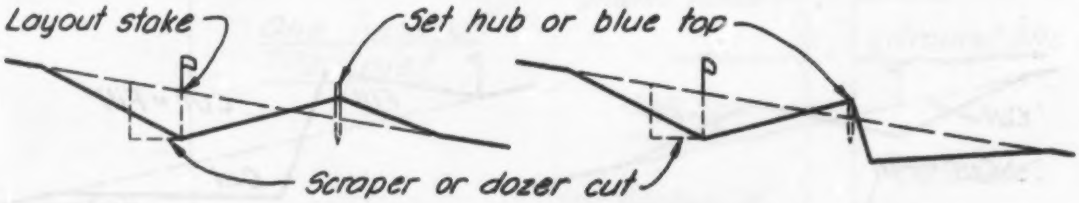


Figure 8-69 Location of stakes for excess borrow sections

A notation should be placed on the layout stakes for underground outlet terraces showing the cut or fill to both the completed channel and ridge.

Excess Fill Section

Where large fills are required at a section, there will not be enough borrow, so borrow must be moved in. Borrow areas need not be confined to terrace channels. Additional borrow, as needed, may be obtained from adjacent high areas. The amount of cut or fill should be placed on the original layout stakes. (Figure 8-70)

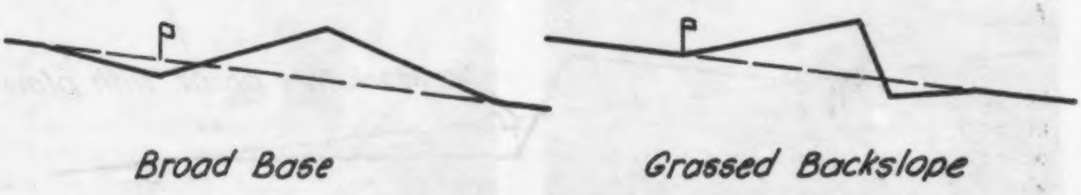


Figure 8-70 Location of stakes for excess fill sections

In some cases, fill at the section may be so high as to require a longer than usual front slope. When this happens the original stake will be covered during construction. Therefore, a reference stake should be set to reference both the alignment and grade. See Figure 8-71.

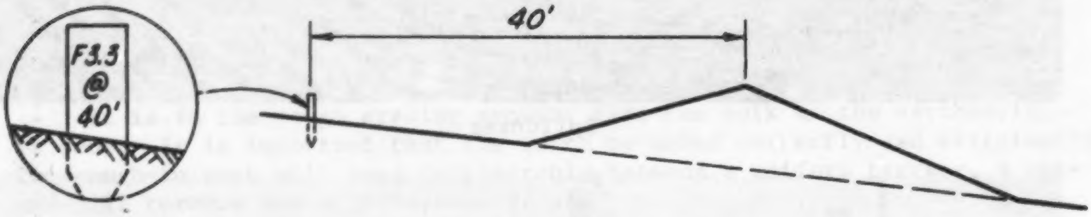


Figure 8-71 Reference stake

PRESERVING THE SURVEY

It is necessary on jobs requiring heavy cuts and fills to set additional reference stakes to preserve the survey and guide the contractor. A hub or temporary bench mark should be established for each terrace, especially when it is a storage-type terrace. They will help reestablish the survey in the event some of the stakes are destroyed during construction.

EARTHMOVING

In the earthmoving process, there are several factors which should be considered. These are the equipment used, the problem with trash and vegetation, the saving of topsoil, the rough grading and the finish grading.

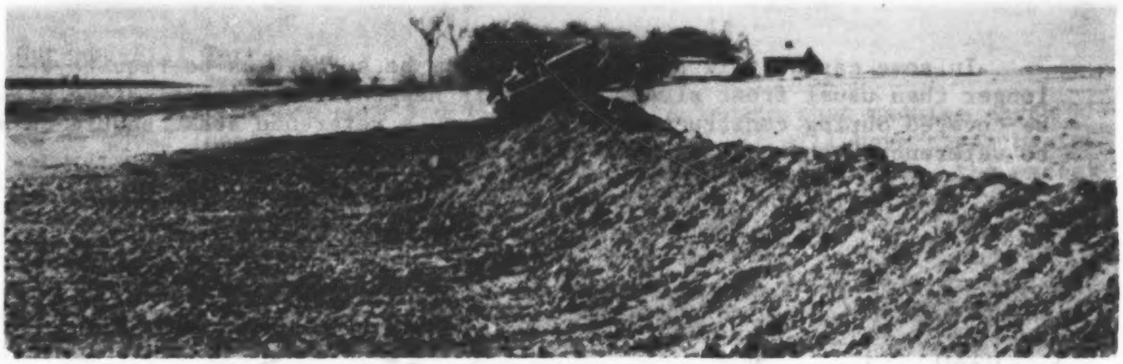
Equipment

There are many types of equipment used to build terraces, ranging from farm equipment to large earthmoving tractors and scrapers. If the terrace has a broad base cross section and has no earth to be moved longitudinally along the terrace line, a bulldozer, road patrol, or disk terracer can be used.

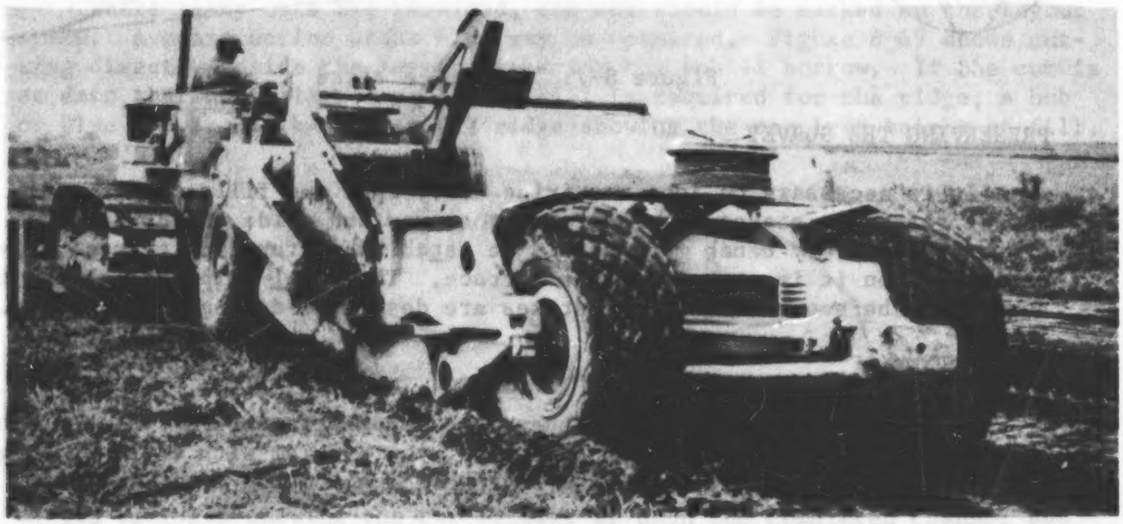
If cuts and fills are involved, earth will need to be moved along the terrace, and hauling equipment will work best. The tractor and scraper best fit these needs. However, if length of haul does not exceed 150 feet, it may be just as economical to use a bulldozer.

Trash and Vegetation

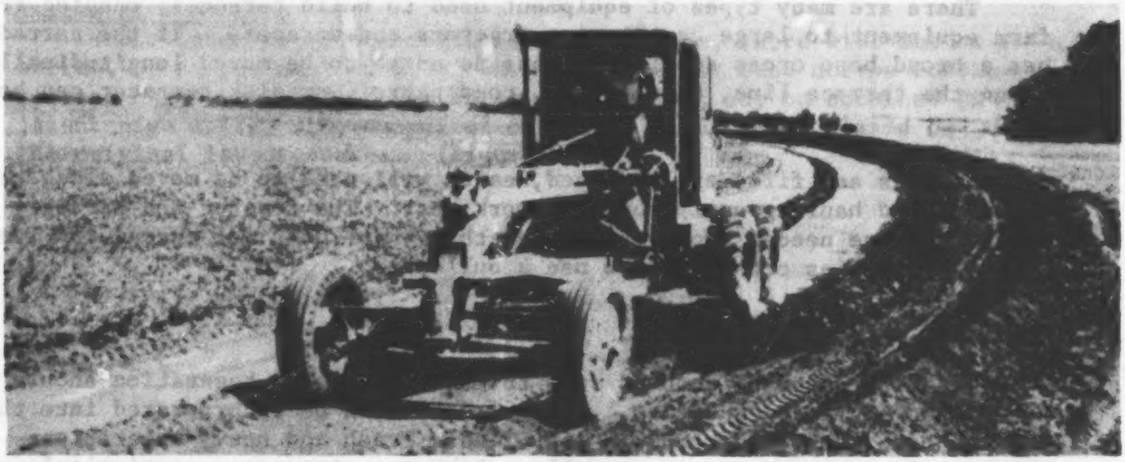
Trash needs to be removed from the terrace base. Vegetation should be removed if it is excessive. Otherwise, it can be incorporated into the terrace base when the ground is scarified. Trash and heavy vegetation otherwise can cause a seepage problem on storage terraces, particularly where fills are high, the borrow is taken from the downhill side, and the back slope is left steep.



Bulldozer



Scraper



Road patrol

Figure 8-72 Types of earthmoving equipment for terraces

Saving Topsoil

Where cuts are heavy and unfavorable subsoil will be exposed, it may be desirable to save the topsoil and respread it over the subsoil areas. One method is to plow the area where topsoil is to be saved, especially when the land is in legume or sod. Then, a dozer can push back the top eight inches of soil. The plowing makes it easier to move the topsoil and gives the dozer operator a guide depth.

Rough Grading

It is in the rough grading process that the bulk of the earthmoving is done. It is important that the earth be moved correctly and efficiently. The rough-in work will vary considerably between a uniform terrace, a cut-and-fill terrace and a grass back slope.

Balanced Section Terrace

Most terraces of this type are roughed in with a dozer. It is important that sufficient cut be made to obtain the desired cross section. If it is not, the error will probably not be discovered until after the terface is finished.

Cut-and-Fill Terrace

Experience on the part of the contractor is the best asset. In lieu of experience, the following steps should be helpful. These assume the use of a dozer and a tractor with a scraper.

1. Doze the earth into the ridge on those parts of the terrace which have balanced sections. Check the channel cut to make sure it is almost correct. Check the cut on the downhill borrow on terraces with grass back slopes.

2. Doze that portion of the earth which is available into the ridge on those sections where excess fill is required. Check to see that the specified amount of cut has been made.

3. Move the excess borrow from the heavy cut areas to the excess fill stations. The key to this type of construction is to build or create a guide by borrowing right down beside the channel stakes to get the channel to the exact elevation.

   This requires checking at each station. Once this exa channel grade has been established, it is easy to see what remains to be done, and much easier to determine when the work is done correctly. This process gives a flat bottom 8 or 10 feet wide which is easily corrected later during the rest of the borrowing.

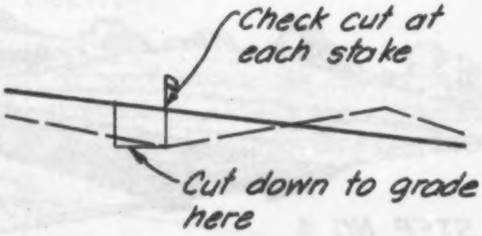
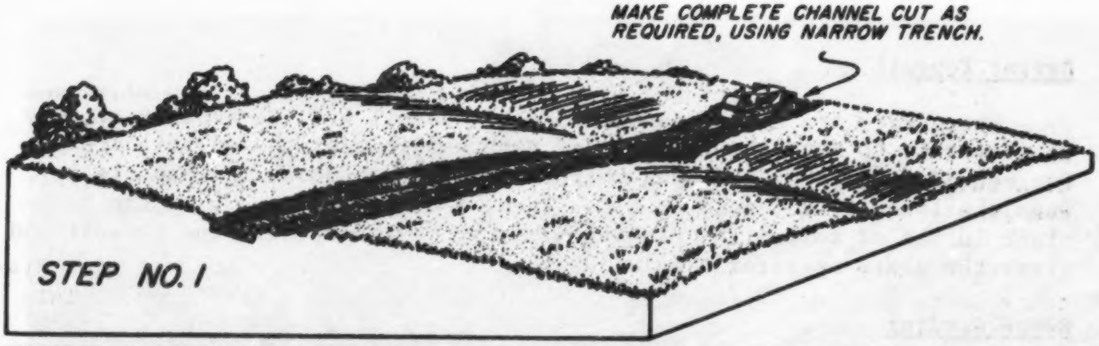
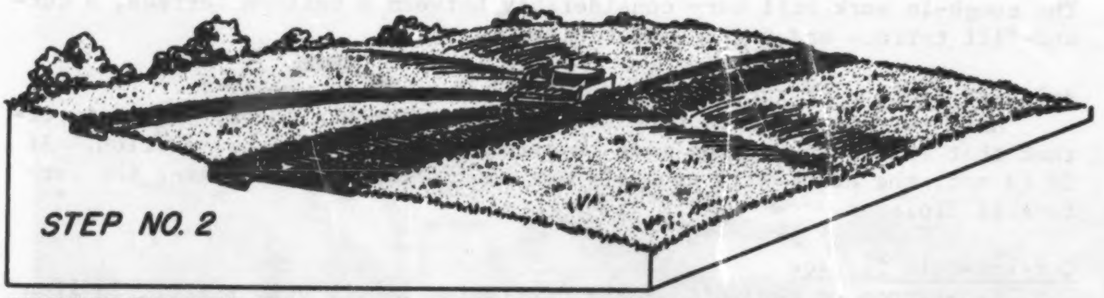


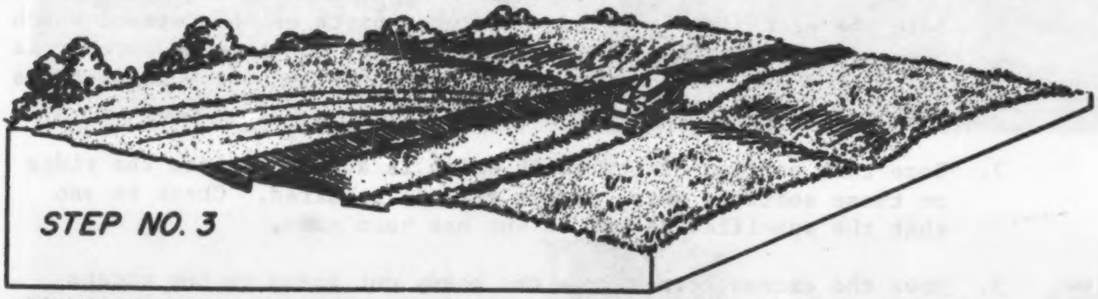
Figure 8-73 Guide for construction


MAKE COMPLETE CHANNEL CUT AS REQUIRED, USING NARROW TRENCH.
STEP NO. 1

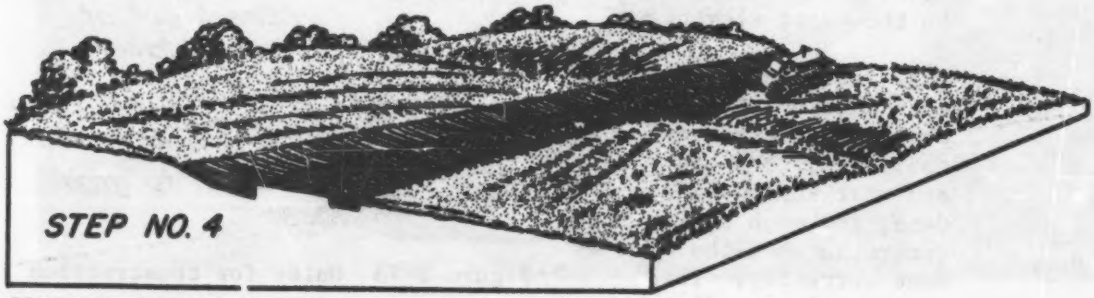
THE DEPTH OF CUT ALONG THE TRENCH WILL BE THAT SHOWN AS DEPTH OF CUT AT EACH 50 FT. STATION. THE EARTH FROM THIS CUT IS PUSHED INTO TERRACE RIDGE WHICH IS BUILT ACROSS THE LOW AREAS IN THE FIELD WHERE FILL IS REQUIRED IN THE TERRACE CONSTRUCTION.



CONSTRUCT THE SLOPE UPHILL FROM THE CHANNEL. START THE CUT UPHILL AT EACH STATION AT A DISTANCE OF DEPTH OF CUT, TIMES 10 PLUS 10 FT. THE FIRST CUT WILL BE PUSHED DIAGONALLY DOWNHILL TOWARD THE PART OF THE TERRACE REQUIRING FILL. SUCCESSIVE CUTS WILL BE MADE BY MOVING DOWNHILL UNTIL SLOPING INTERSECTS CHANNEL.



AFTER THE SLOPING IS COMPLETED ON THE UPHILL SIDE, THE CHANNEL FORESLOPE CAN BE PROPERLY SLOPED. ANY ADDITIONAL FILL NEEDED TO COMPLETE THE TERRACE CAN BE TAKEN FROM THE DOWNHILL SIDE OF THE TERRACE ON FIELD RIDGES.



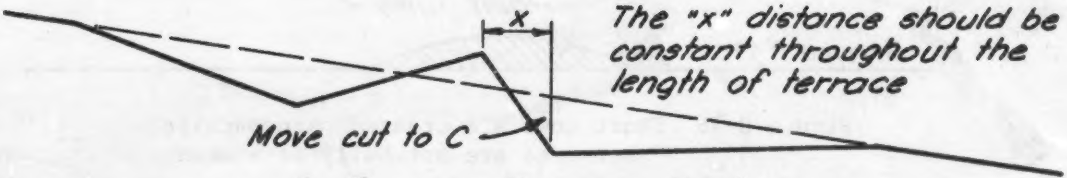
COMPLETE TERRACE BY DRESSING UP SLOPES WITH DOZER.

Figure 8-74 Using a dozer to build terraces having cuts and fills

Grass Back Slope

On the terraces with grass back slopes, most of the borrow will come from the downhill side. As much as possible should be dozed into place. When the haul gets too long, a tractor and scraper should be used instead of a bulldozer. The ridges and highs on the downhill side of the terrace are excellent places to borrow. Again, save topsoil if necessary.

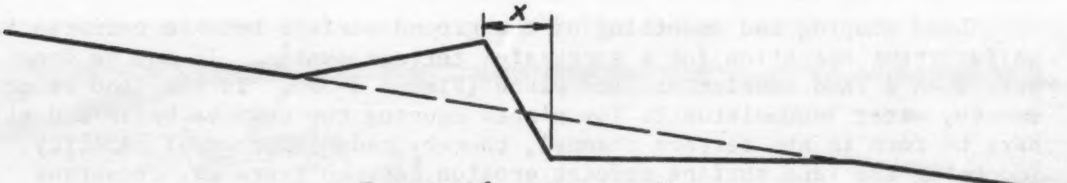
Some contractors have a tendency to want to use the shortest haul distance instead of using the ridges and high points for borrow areas. This practice will result in a back slope of varying width along the terrace, and the system will have short rows and poor farmability. See Figure 8-75.



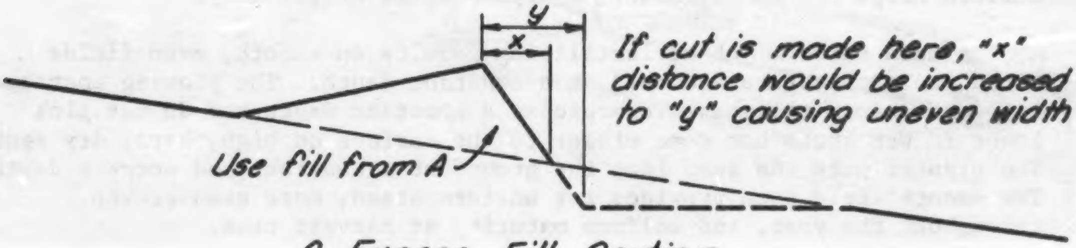
The "x" distance should be constant throughout the length of terrace

Move cut to C

A. Excess Borrow Section



B. Uniform Section



If cut is made here, "x" distance would be increased to "y" causing uneven width

Use fill from A

C. Excess Fill Section

Figure 8-75 Methods of borrow

Rough Grading Check

The final step in rough grading is to make sure there is enough earth in the ridge to bring it up to height and cross section, considering settlement and compaction. It is important that the contractor check the ridge for approximate height before proceeding to the finishing operation. On level terraces and underground outlet terraces the ridge should be level throughout its length (except in those few cases where the terrace is quite long and there is no storage in the outer ends of the terrace).

FINISHING TERRACE CROSS SECTION

Finishing is usually done with a dozer, but can be done with a motor grader. Cut slopes, front slopes and back slopes should be finished to their planned dimensions. Parallel terraces should be finished in parallel, as any mistake in alignment on a terrace affects two terrace intervals. See Figure 8-76.

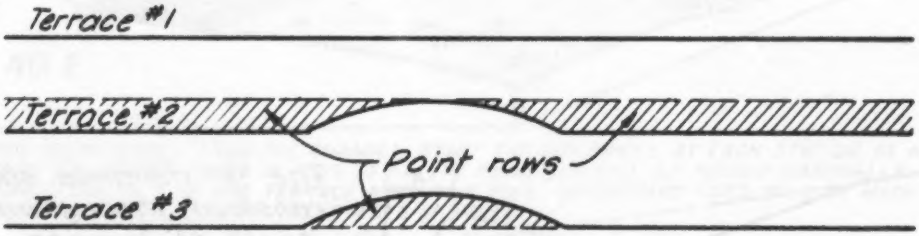


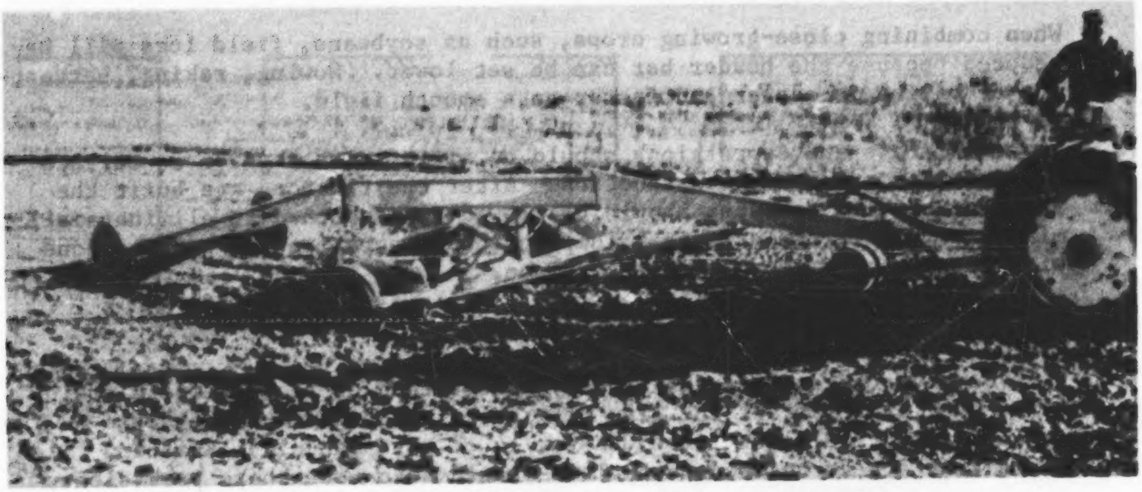
Figure 8-76 Short rows are created when parallel terraces are not built as staked

SMOOTHING AND SHAPING

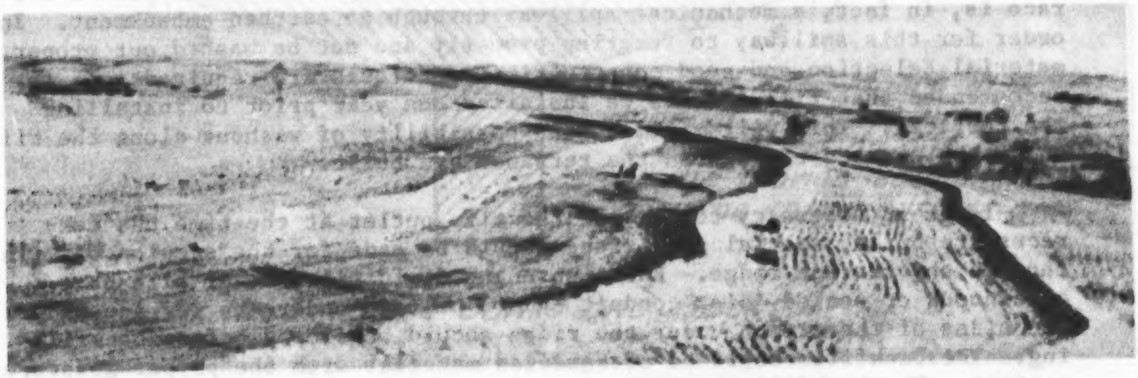
Land shaping and smoothing of the ground surface between terraces is an important operation for a successful terrace system. It can be done best with a land leveler or land plane (Figure 8-77). If the land is not smooth, water accumulates in low places causing the rows to break and silt bars to form in the terrace channel, thereby reducing channel capacity. Smoothing the land surface reduces erosion between terraces, conserves moisture, provides for better farming by making it possible to grow more uniform crops and to use modern equipment more efficiently.

A more uniform job of fertilizing results on smooth, even fields since the applicators are held at a constant depth. The plowing operation is better since the shares operate at a constant depth and do not sink lower in wet spots nor come closer to the surface on high, hard, dry spots. The planter puts the seed into the ground at a constant and correct depth. The smooth field then provides for uniform stand, more even growth throughout the year, and uniform maturity at harvest time.

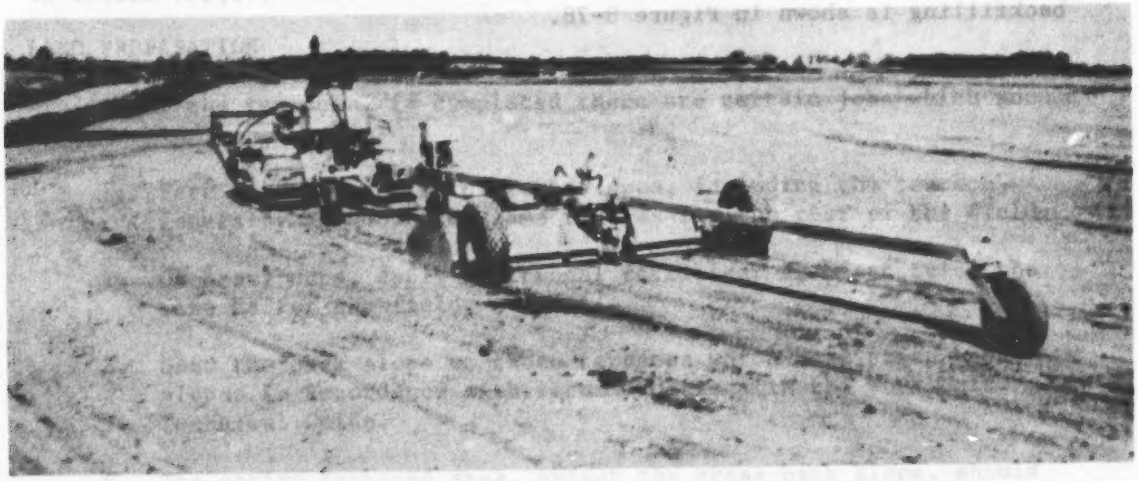
A smooth seedbed permits closer and more complete cultivation since the tractor and cultivater gage wheels are working on a smooth surface.



Shaping Between Terraces with a Land Leveler



Comparison of Smoothed and Rough Terrace Intervals



Finishing a Terraced Field with a Land Plane

Figure 8-77 Equipment for land smoothing

When combining close-growing crops, such as soybeans, field loss will be reduced because the header bar can be set lower. Mowing, raking, harvesting or baling is easier and faster on a smooth field.

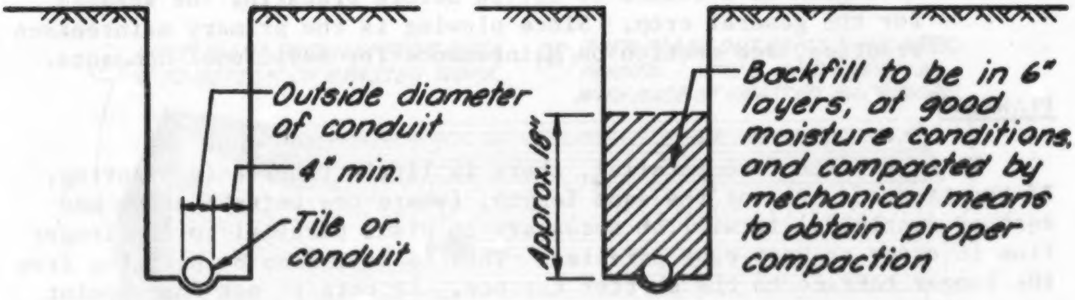
All draws and depressions should be filled either prior to terrace construction or during construction. After the terraces are built the area between the terraces should be plowed and smoothed to eliminate all minor surface irregularities. The smoothing operation can best be done with some type of land leveler or plane.

INSTALLATION OF UNDERGROUND OUTLET

Underground outlets are usually constructed of regular field drain tile. At least part of the line will be on steep grades and should be installed as a tile main. (See Chapter 14 of this manual.) Existing tile lines that are to be used as outlets should also meet these provisions.

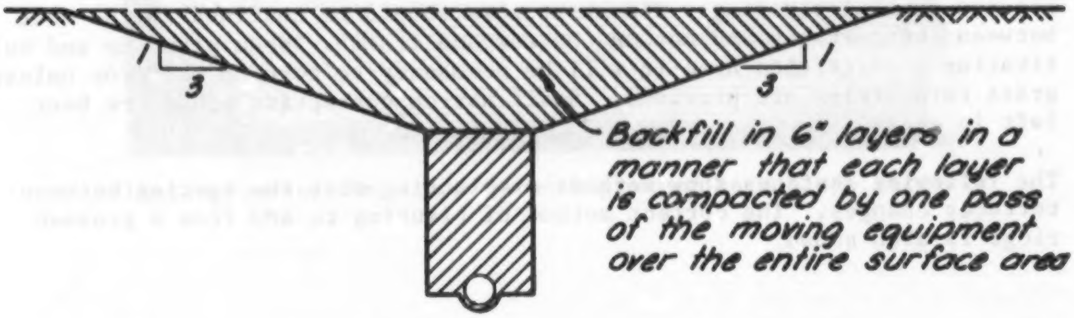
The Underground outlet used to dispose of impounded water from a terrace is, in fact, a mechanical spillway through an earthen embankment. In order for this spillway to function properly and not be washed out proper material selection and good construction techniques are required. It is recommended that tile outlets be installed one year prior to installing the terraces. This will minimize the possibility of washout along the tile under the terrace ridge when the terraces are built.

If it is necessary to install the tile outlet at the time the terraces are built, special provisions should be made for the section of tile through the terrace ridge. Extra strength field tile, sewer tile or continuous or sealed joint conduit should be laid under the terrace ridge. The sides of the trench under the ridge should be sloped before backfilling. The backfill should be of selected material with the proper moisture content. The backfill should be placed in layers not more than six inches thick and each layer mechanically compacted. Another accepted method of backfilling is shown in Figure 8-78.


Outside diameter of conduit
4" min.
Tile or conduit
Approx. 18"
Backfill to be in 6" layers, at good moisture conditions, and compacted by mechanical means to obtain proper compaction

Step No. 1 - Cut Channel and Lay Conduit

Step No. 2 - Initial Backfill


1
3
1
3
Backfill in 6" layers in a manner that each layer is compacted by one pass of the moving equipment over the entire surface area

Step No. 3 - Slope Banks and Backfill

Figure 8-78 A method of backfilling the underground conduit trench

13. FARMING

LAND PREPARATION

After the terracing is completed there are certain jobs which should be done.

1. Fertilize the entire disturbed area, including the terrace, generally at about the same rate as for the rest of the field.

2. On heavy cuts, apply additional fertilizer at least twice the rate as for the field.

3. Seed the back slope on those terraces which have steep back slopes in accordance with recommendations in the Work Unit Technical Guide.

4. The entire terraced area, except the grass back slope, should be plowed to loosen the soil compacted by the earthmoving machinery. The quicker it can be plowed the better since this

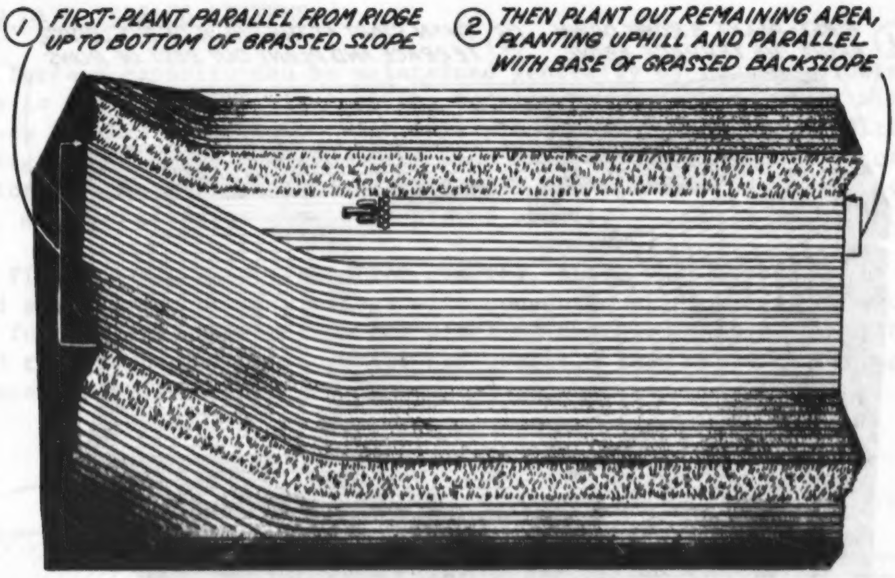
will give it a chance to mellow before preparing the seedbed for the general crop. Since plowing is the primary maintenance practice, see section on Maintenance for additional comments.

PLANTING

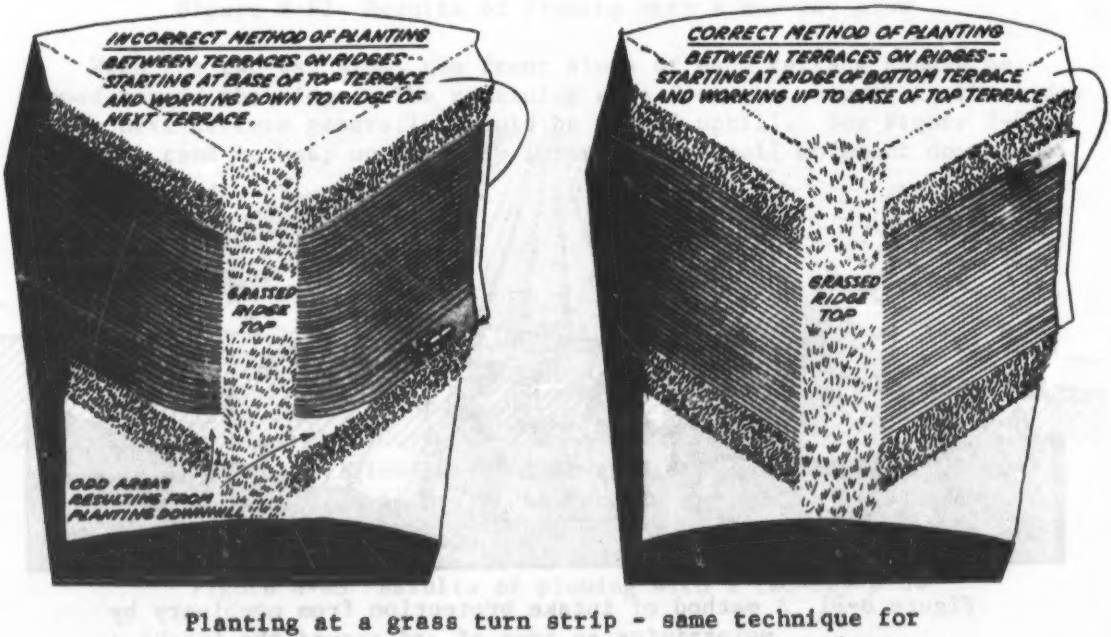
Where terraces are parallel, there is little trouble in planting. If the terraces are not the same length, (where one terrace stops and another continues) it will be necessary to plant parallel to the longer line in order to keep rows parallel. This is best done by planting from the longer terrace to the shorter terrace. If this is not done, point rows will develop. If it is not possible to plant from the longer terrace line toward the shorter, it will be necessary to plant parallel to the longer line.

If terraces are not parallel, correction areas are necessary and these require special planting. The short rows should be confined to the area between the terraces and not on the terrace itself. When planting and cultivating a correction area it will be necessary to turn on the crop unless grass turn strips are provided. Small narrow correction areas are best left in grass.

The following sketches show methods of planting when the spacing between terraces changes. The correct method of planting to and from a grassed ridge is also shown.


① FIRST-PLANT PARALLEL FROM RIDGE UP TO BOTTOM OF GRASSED SLOPE
② THEN PLANT OUT REMAINING AREA, PLANTING UPHILL AND PARALLEL WITH BASE OF GRASSED BACKSLOPE

Planting correction areas between grassed back slope terraces


INCORRECT METHOD OF PLANTING BETWEEN TERRACES ON RIDGES-- STARTING AT BASE OF TOP TERRACE AND WORKING DOWN TO RIDGE OF NEXT TERRACE.
GRASSED RIDGE TOP
ODD AREAS RESULTING FROM PLANTING DOWNHILL
CORRECT METHOD OF PLANTING BETWEEN TERRACES ON RIDGES-- STARTING AT RIDGE OF BOTTOM TERRACE AND WORKING UP TO BASE OF TOP TERRACE
GRASSED RIDGE TOP

Planting at a grass turn strip - same technique for both grassed back slope and broad base sections

Figure 8-79 Planting grassed back slope terraces

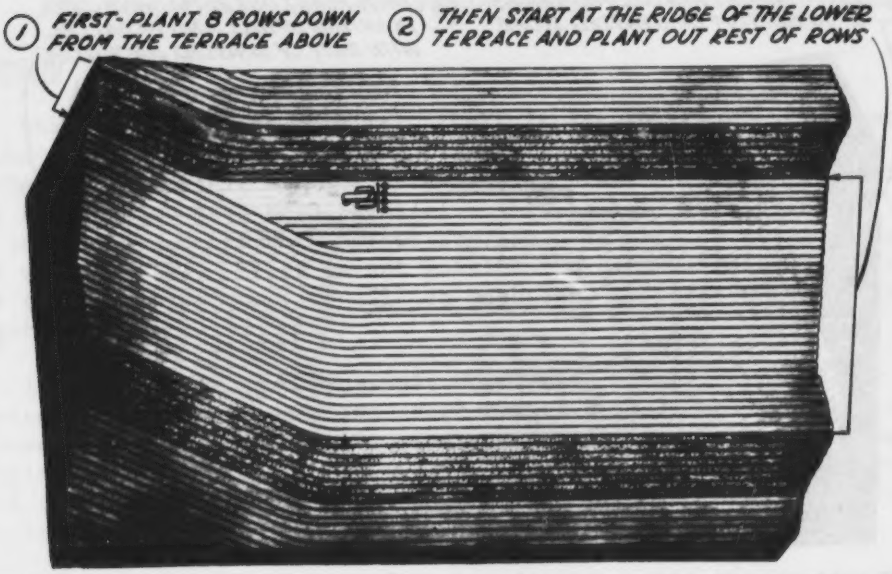

① FIRST - PLANT 8 ROWS DOWN FROM THE TERRACE ABOVE
② THEN START AT THE RIDGE OF THE LOWER TERRACE AND PLANT OUT REST OF ROWS

Figure 8-80 Planting correction areas between broad base terraces

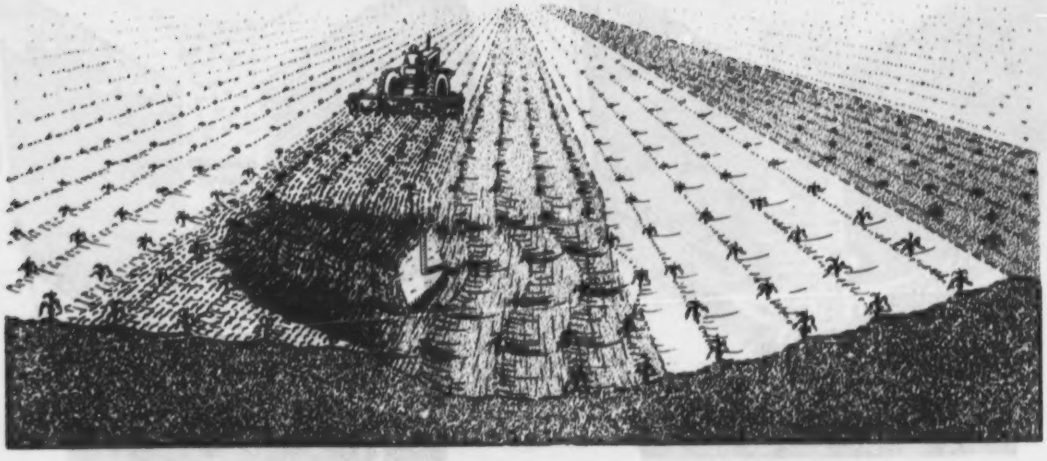


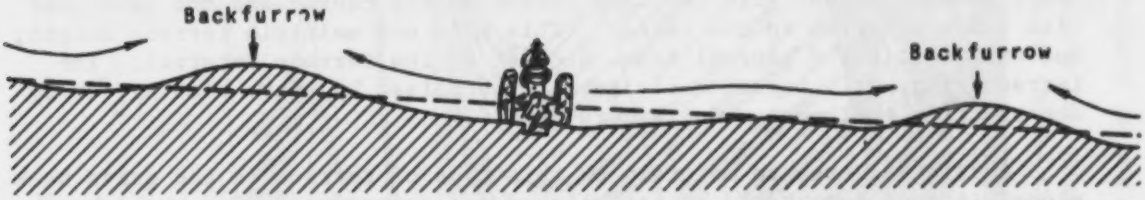
Figure 8-81 A method of intake protection from machinery by maintaining an area of sod around the intake

14. MAINTENANCE

BROAD BASE TERRACE SYSTEMS

Terrace capacity can be maintained generally by routine plowing. There is really no satisfactory way to plow terrace land except with the two-way (reversible) plow. With this plow, soil can be thrown either to the right or to the left depending upon choice. To maintain the cross section of the terraces and the terrace interval as it was after construction, most of the area should be plowed uphill.

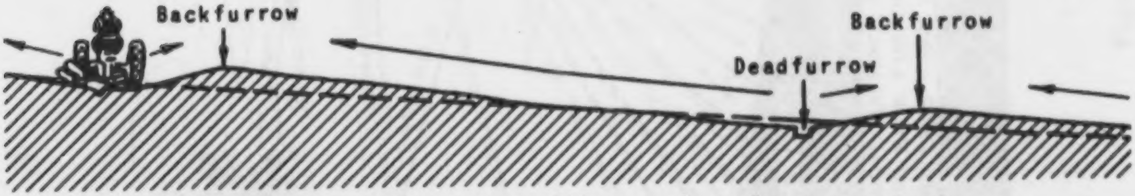
Figure 8-82, exaggerated for clarity, shows what happens to a terraced field after a number of plowings with conventional plows. Even though the dead furrows are shifted from one place to another it is not possible to avoid throwing soil both downhill and uphill. This causes benching of the terrace interval.



By using a one-way plow the profile becomes dished and after a number of plowings the terraces become 'benched' . . . Arrows indicate direction dirt is thrown; the dashed line indicates natural ground level.

Figure 8-82 Results of plowing with a one-way plow

With the two-way plow, the front slope of each terrace should be plowed toward the ridge. The remaining area from the channel to the ridge of the next terrace generally should be plowed uphill. See Figure 8-83. This will tend to keep up with any inter-terrace soil movement downslope.



By using a two-way plow the profile remains almost constant . . . Arrows indicate direction dirt is thrown; the dashed line indicates natural ground level.

Figure 8-83 Results of plowing with a two-way plow

Unfortunately, there are very few farmers with two-way plows. The trend in farm machinery is to larger tractors pulling 5-, 6-, and 8-bottom standard plows. The best that can be done with a standard plow is to plow so that dead furrows do not fall in the same place too often. Either the terrace ridge should be raised by backfurrowing each time the field is plowed, or the channel deepened by dead furrowing. One of these two is necessary. If the terrace height or capacity is very low, place both a dead furrow in the channel and a backfurrow on the ridge. This is best accomplished with the conventional plow by the "Three land method." With this method the area between terraces is divided into three "lands" and each land is plowed separately in progressive steps as illustrated in Figure 8-84.

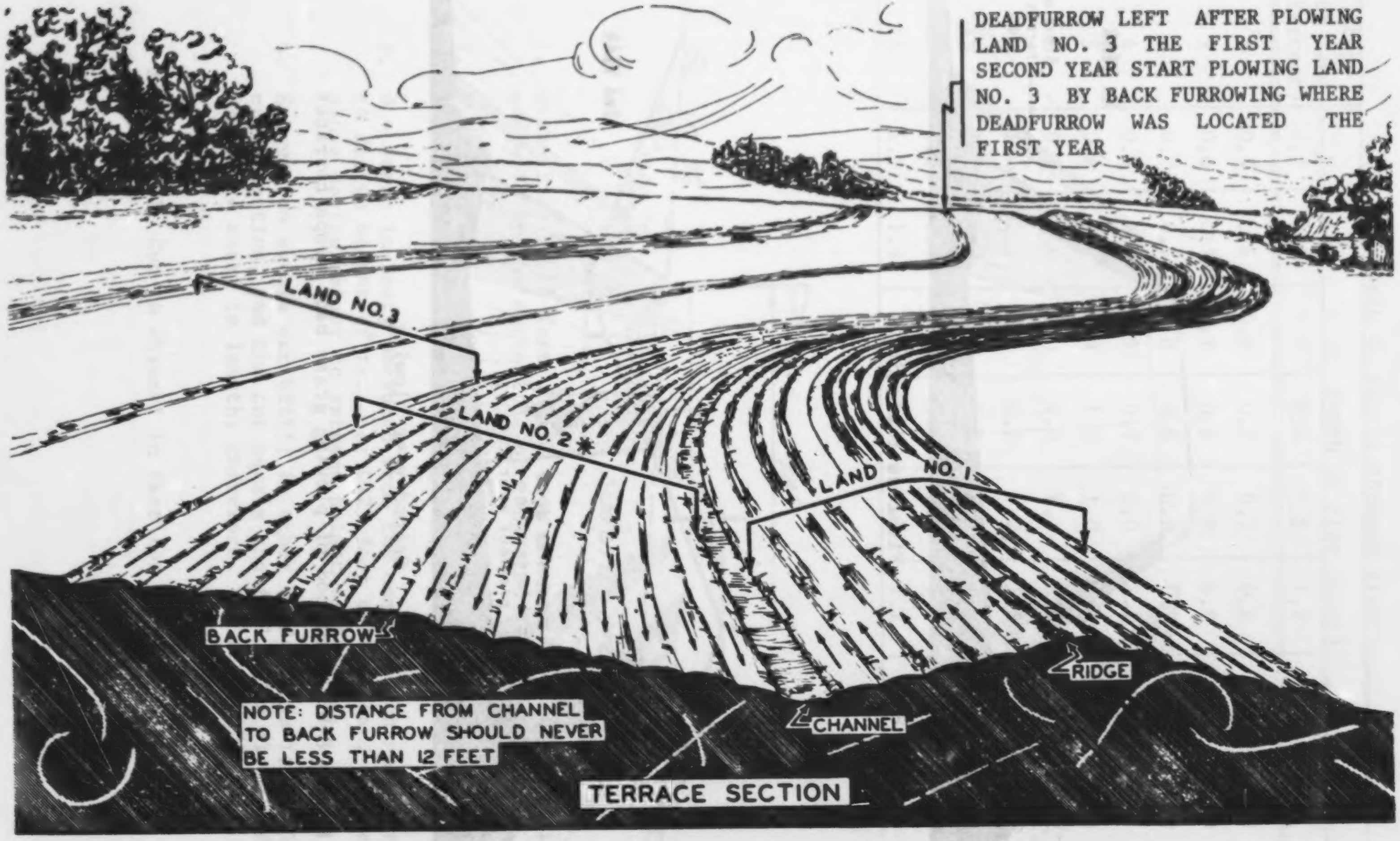
TERRACES WITH GRASS BACK SLOPES

Maintenance of terraces with grass back slopes is considerably different. Plowing is easier, in that the land can be plowed more like level land, one year with the dead furrow in the center and the next year with the backfurrow in the center. This will not maintain terrace height, but will retain the general cross section of the terrace interval. The terrace ridge will occasionally have to be raised by extra plowing, or by construction equipment. See Figure 8-85.

A critical area to maintain on this type of terrace is the grass back slope. A good sod should be established and maintained. Trees and brush growth should be controlled by spraying, or mowing if possible. Gophers and burrowing rodents should be eliminated from the slope. The slope should be fertilized occasionally to maintain a vigorous sod.

MAINTENANCE BY HEAVY EQUIPMENT

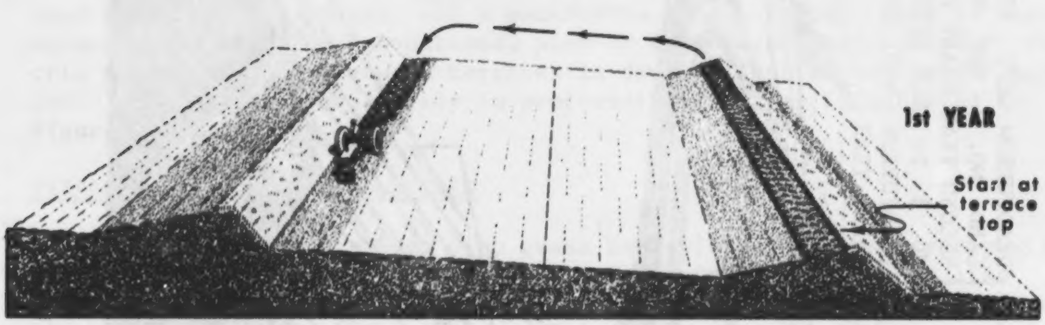
As farms increase in size and as farm machinery becomes larger and more specialized (less useful for terrace maintenance), maintenance by construction machinery is both desirable and recommended. The road patrol is an excellent tool for this type of reconstruction. The trend in many areas is for farmers to hire terrace maintenance rather than to do it themselves.


DEADFURROW LEFT AFTER PLOWING LAND NO. 3 THE FIRST YEAR SECOND YEAR START PLOWING LAND NO. 3 BY BACK FURROWING WHERE DEADFURROW WAS LOCATED THE FIRST YEAR
LAND NO. 3
LAND NO. 2 *
LAND NO. 1
BACK FURROW
RIDGE
NOTE: DISTANCE FROM CHANNEL TO BACK FURROW SHOULD NEVER BE LESS THAN 12 FEET
CHANNEL
TERRACE SECTION

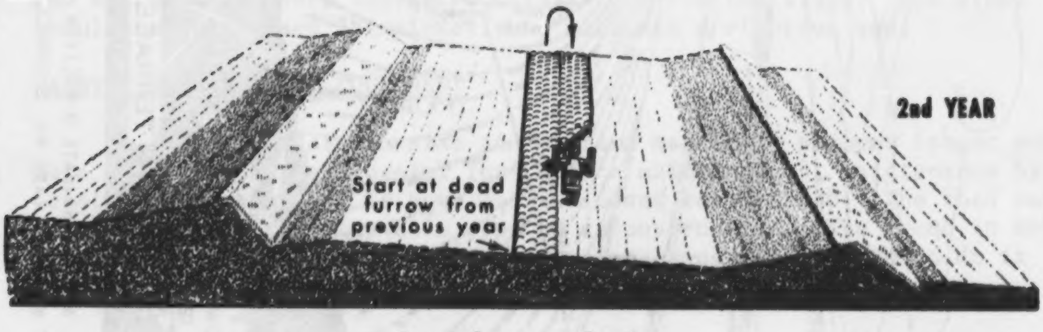
ARROWS INDICATE DIRECTION IN WHICH FURROWS ARE MADE

* WIDTH OF LAND NO. 2 SHOULD BE VARIED EACH PLOWING

Figure 8-84 The three land method of plowing terraces


1st YEAR
Start at terrace top

First year plowing

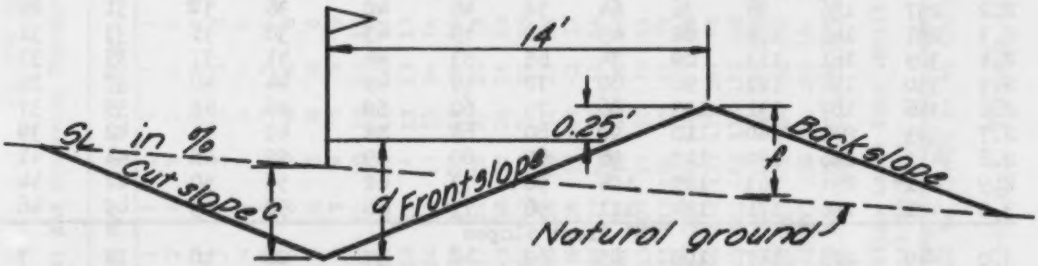

2nd YEAR
Start at dead furrow from previous year

Second year plowing

Figure 8-85 A method of plowing grass back slope terraces

Depth of cut in channel (feet)

Slope of land (Percent)	Depth of flow (feet)								
	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
1	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9
2	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0
3	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1
4	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2
5	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2
6	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3
8	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4
10	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6
12	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7
14	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9



1. Stake line is 14 feet uphill from the completed terrace ridge and will be the centerline of completed "V" channel.

2. c - cut in channel in feet, measured from the natural ground at the stake line to the completed channel bottom.

3. d - depth in feet, measured from the completed channel bottom to design height of terrace; 0.25 foot of freeboard allowed above design height to extreme height of terrace.

4. Excavation equals earthfill; in other words, this is a balanced cross section, and the cut equals the fill. Cut slope and back slope are equal in length; therefore, "c" equals "f."

Exhibit 8-1 Cut in channel in feet for broad base terraces

NATURAL STORAGE ABOVE TERRACES
IN CU. FT. PER LINEAL FOOT

S_L d	1%	2%	3%	4%	5%	6%	8%	10%	12%	14%	16%	18%
						14' Front Slopes						
0.1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	3	2	2	2	2	2	2	2	2	2	2	2
0.3	7	4	4	3	3	3	3	3	3	2	2	2
0.4	11	7	6	5	4	4	4	4	4	3	3	3
0.5	16	10	8	7	6	6	5	5	5	4	4	4
0.6	22	13	10	9	8	7	6	6	6	6	5	5
0.7	29	17	13	11	10	9	8	7	7	7	6	6
0.8	38	22	16	14	12	11	10	9	8	8	8	7
0.9	47	27	20	16	14	13	11	10	10	9	9	9
1.0	57	32	24	20	17	15	13	12	11	11	10	10
1.1	68	38	28	23	20	18	15	14	13	12	12	11
1.2	80	44	32	26	23	20	17	16	14	14	13	12
1.3	94	51	37	30	26	23	20	18	16	15	14	14
1.4	108	59	43	34	29	26	22	20	18	17	16	15
1.5	123	67	48	39	33	29	25	22	20	19	18	17
1.6	139	75	54	43	37	33	27	24	22	20	19	18
1.7	156	84	60	48	41	36	30	26	24	22	21	20
1.8	175	94	67	53	45	40	33	29	26	24	23	22
1.9	194	104	74	58	49	43	36	31	28	26	25	24
2.0	214	114	81	64	54	47	39	34	31	28	26	25
2.1	235	125	88	70	59	51	42	37	33	30	28	27
2.2	257	136	96	76	64	56	46	40	36	32	31	29
2.3	281	148	104	82	69	60	49	43	38	35	33	31
2.4	305	161	113	89	74	65	53	46	41	37	35	33
2.5	330	174	122	96	80	70	57	49	44	40	37	35
2.6	356	187	131	103	86	75	60	52	46	42	39	37
2.7	383	201	140	110	92	80	65	55	49	45	42	39
2.8	412	216	150	117	98	85	69	59	52	48	44	41
2.9	441	231	161	125	104	90	73	62	55	50	47	44
3.0	471	246	171	134	111	96	77	66	58	53	49	46
						28' Front Slopes						
3.0	449	223	147	109	85	69	48	37	26	18	12	7
3.2	511	254	168	124	97	79	56	41	31	23	16	11
3.4	577	287	190	141	111	90	64	48	36	28	20	14
3.6	647	322	213	158	125	102	73	55	42	33	25	18
3.8	721	359	238	177	139	114	82	62	48	38	29	22
4.0	799	398	264	196	155	127	92	70	55	43	34	27
5.0	1250	623	414	309	245	202	148	115	92	76	62	52
6.0	1800	898	597	446	355	294	217	170	138	115	97	82
7.0	2450	1220	814	609	485	402	298	235	192	161	137	118
8.0	3200	1600	1060	796	635	527	392	310	255	215	184	160
9.0	4050	2020	1350	1010	805	669	498	395	326	276	237	207

1. **Storage shown is natural storage, storage above natural ground on uphill side of the terrace. Does not include any storage which might result from excavation.**

2. **S_L - slope of the land where the terrace is built.**

3. **d - depth of water in the completed terrace, measured from the natural ground at the stakeline to the top of the terrace ridge.**

4. **This table is based entirely on a stakeline placed 14 ft. uphill from the completed terrace ridge. Stated another way, peak of the terrace ridge is always built 14 ft. downhill from stakeline for both 14' and 28' frontslopes.**

Exhibit 8-2 Natural storage above terrace
(cu.ft./lin.ft.)

1% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	.1	.2	.3	.4	.5	.6	.7	.8	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	7	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	11	7	5	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	16	12	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	22	17	12	9	7	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	29	23	18	13	10	8	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	38	30	24	18	14	11	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	47	38	31	25	19	15	12	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	57	48	39	32	26	20	16	13	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	68	58	48	40	33	27	21	17	14	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	80	69	59	49	41	34	28	23	18	16	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	94	81	70	59	50	42	35	29	24	20	17	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	108	94	82	71	60	51	43	36	30	25	21	18	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	123	109	95	83	72	61	52	44	37	31	26	22	20	18	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
1.6	139	124	109	96	84	73	62	53	45	38	32	28	24	21	20	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
1.7	156	140	125	110	97	85	74	64	54	47	40	34	29	25	23	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
1.8	175	157	141	125	111	98	86	75	65	56	48	41	35	31	27	24	23	22	22	22	22	22	22	22	22	22	22	22	22	22
1.9	194	175	158	142	126	112	99	87	76	66	57	49	42	37	32	29	26	25	24	24	24	24	24	24	24	24	24	24	24	24
2.0	214	195	176	159	143	127	113	100	88	77	67	58	51	44	38	34	30	28	26	26	26	26	26	26	26	26	26	26	26	26
2.1	235	215	195	177	160	144	128	114	101	89	78	69	60	52	46	40	35	32	30	28	28	28	28	28	28	28	28	28	28	28
2.2	257	236	216	196	178	161	145	130	115	103	91	80	70	61	54	47	42	37	34	31	30	30	30	30	30	30	30	30	30	30
2.3	281	258	237	216	197	179	162	146	131	117	104	92	81	72	63	55	49	43	39	36	33	32	32	32	32	32	32	32	32	32
2.4	305	281	259	238	217	198	180	163	147	132	118	105	93	83	73	65	57	51	45	41	38	35	34	34	34	34	34	34	34	34
2.5	330	306	282	260	239	218	199	181	164	148	133	119	107	95	84	75	66	59	52	47	43	40	37	36	36	36	36	36	36	36
2.6	356	331	306	283	261	240	219	200	182	165	149	135	121	108	97	86	76	68	60	54	49	45	42	40	39	39	39	39	39	39
2.7	383	357	332	307	284	262	241	221	201	184	167	151	136	122	110	98	88	78	70	62	56	51	47	44	42	41	41	41	41	41
2.8	412	384	358	332	308	285	263	242	222	203	185	168	152	138	124	111	100	89	80	72	64	58	53	49	46	44	43	43	43	43
2.9	441	412	385	359	333	309	286	264	243	223	204	186	169	154	139	126	113	102	91	82	74	66	60	55	51	48	46	46	46	46
3.0	471	442	413	386	360	334	310	287	265	244	224	205	188	171	155	141	127	115	103	93	84	76	68	62	57	53	51	49	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in the completed terrace, measured from the completed channel bottom to the top of the terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 1 of 8)

5,L-24726.2

2% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	7	5	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	10	8	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	13	11	8	7	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	17	14	11	9	8	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	22	18	15	12	10	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	27	22	19	16	13	11	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	32	27	23	20	17	14	12	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	38	33	28	24	21	18	15	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	44	39	34	29	25	22	19	16	15	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	51	45	40	34	30	26	23	20	18	16	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	59	52	46	40	35	31	27	24	21	19	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	67	60	53	47	41	36	32	28	25	22	20	19	18	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
1.6	75	68	60	54	48	42	37	33	29	26	24	22	20	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
1.7	84	76	68	61	55	49	43	39	34	31	28	25	23	22	21	21	21	21	21	21	21	21	21	21	21	21	21	21
1.8	94	85	77	69	62	56	50	45	40	36	32	29	27	25	23	23	22	22	22	22	22	22	22	22	22	22	22	22
1.9	104	94	86	78	70	63	57	51	46	41	37	33	31	28	26	25	24	24	24	24	24	24	24	24	24	24	24	24
2.0	114	104	95	87	79	71	64	58	52	47	42	38	35	32	30	28	27	26	26	26	26	26	26	26	26	26	26	26
2.1	125	115	105	96	88	80	72	65	59	54	48	44	40	37	34	31	30	29	28	28	28	28	28	28	28	28	28	28
2.2	136	126	116	106	97	89	81	73	67	60	55	50	45	41	38	35	33	32	30	30	30	30	30	30	30	30	30	30
2.3	148	137	127	116	107	98	90	82	75	68	62	56	51	47	43	40	37	35	33	32	32	32	32	32	32	32	32	32
2.4	161	149	138	127	117	108	99	91	83	76	69	63	58	53	49	45	42	39	37	35	34	34	34	34	34	34	34	34
2.5	174	162	150	139	128	118	109	100	92	84	77	71	65	59	54	50	47	43	41	39	37	37	36	36	36	36	36	36
2.6	187	175	162	151	140	129	119	110	101	93	86	79	72	66	61	56	52	48	45	43	41	40	39	39	39	39	39	39
2.7	201	188	175	163	152	141	130	121	111	103	95	87	80	74	68	63	58	54	50	47	45	43	42	41	41	41	41	41
2.8	216	202	189	176	164	153	142	132	122	113	104	96	89	82	75	70	64	60	56	52	49	47	45	44	43	43	43	43
2.9	231	216	203	190	177	165	154	143	133	123	114	105	98	90	83	77	71	66	62	58	54	51	49	47	46	46	46	46
3.0	246	231	217	204	191	178	166	155	144	134	124	115	107	99	92	85	79	73	68	64	60	56	54	51	50	49	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in the completed terrace, measured from completed channel bottom to the top of the terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 2 of 8)

3% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	6	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	8	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	10	8	7	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	13	11	9	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	16	14	12	10	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	20	17	15	13	11	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	24	21	18	16	14	12	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	28	24	21	19	17	15	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	32	29	25	22	20	18	16	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	37	33	29	26	23	21	19	17	16	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	43	38	34	30	27	24	22	20	18	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	48	43	39	35	31	28	25	23	21	20	18	18	17	17	17	17	17	17	17	17	17	17	17	17	17	17
1.6	54	49	44	40	36	32	29	27	24	22	21	20	19	19	19	19	19	19	19	19	19	19	19	19	19	19
1.7	60	55	50	45	41	37	33	30	28	26	24	22	21	21	21	21	21	21	21	21	21	21	21	21	21	21
1.8	67	61	55	50	46	42	38	35	32	29	27	25	24	23	22	22	22	22	22	22	22	22	22	22	22	22
1.9	74	67	62	56	51	47	43	39	36	33	31	28	27	26	25	24	24	24	24	24	24	24	24	24	24	24
2.0	81	74	68	63	57	52	48	44	40	37	34	32	30	28	27	26	26	26	26	26	26	26	26	26	26	26
2.1	88	81	75	69	64	58	54	49	45	42	39	36	34	32	30	29	28	28	28	28	28	28	28	28	28	28
2.2	96	89	82	76	70	65	59	55	50	47	43	40	37	35	33	32	31	30	30	30	30	30	30	30	30	30
2.3	104	97	90	83	77	71	66	61	56	52	48	45	42	39	37	35	34	33	32	32	32	32	32	32	32	32
2.4	113	105	98	91	84	78	72	67	62	57	53	49	46	43	41	39	37	36	35	34	34	34	34	34	34	34
2.5	122	114	106	99	92	85	79	73	68	63	59	55	51	48	45	42	40	39	38	37	36	36	36	36	36	36
2.6	131	122	114	107	100	93	86	80	75	69	65	60	56	53	49	47	44	42	41	40	39	39	39	39	39	39
2.7	140	132	123	115	108	101	94	87	81	76	71	66	62	58	54	51	48	46	44	43	42	41	41	41	41	41
2.8	150	141	132	124	116	109	102	95	89	83	77	72	68	63	59	56	53	50	48	46	45	44	43	43	43	43
2.9	161	151	142	133	125	117	110	103	96	90	84	79	74	69	65	61	58	55	52	50	48	47	46	46	46	46
3.0	171	161	152	143	134	126	118	111	104	98	91	86	80	75	71	67	63	60	57	54	52	51	49	49	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in completed terrace, measured from completed channel bottom to the top of the terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 3 of 8)

4% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	5	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	7	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	9	7	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	11	9	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	14	12	10	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	16	14	13	11	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	20	17	15	14	12	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	23	20	18	16	15	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	26	24	21	19	17	16	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	30	27	24	22	20	18	17	16	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	34	31	28	25	23	21	19	18	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	39	35	32	29	26	24	22	20	19	18	18	17	17	17	17	17	17	17	17	17	17	17	17	17
1.6	43	39	36	33	30	27	25	23	22	21	20	19	19	19	19	19	19	19	19	19	19	19	19	19
1.7	48	44	40	37	34	31	28	26	25	23	22	21	21	21	21	21	21	21	21	21	21	21	21	21
1.8	53	49	45	41	38	35	32	30	28	26	25	24	23	22	22	22	22	22	22	22	22	22	22	22
1.9	58	54	50	46	42	39	36	33	31	29	27	26	25	25	24	24	24	24	24	24	24	24	24	24
2.0	64	59	55	51	47	43	40	37	35	32	30	29	28	27	26	26	26	26	26	26	26	26	26	26
2.1	70	65	60	56	52	48	44	41	38	36	34	32	31	29	29	28	28	28	28	28	28	28	28	28
2.2	76	71	66	61	57	53	49	46	42	40	37	35	34	32	31	30	30	30	30	30	30	30	30	30
2.3	82	77	71	67	62	58	54	50	47	44	41	39	37	35	34	33	32	32	32	32	32	32	32	32
2.4	89	83	78	72	67	63	59	55	51	48	45	43	41	39	37	36	35	34	34	34	34	34	34	34
2.5	96	90	84	78	73	69	64	60	56	53	50	47	44	42	40	39	38	37	36	36	36	36	36	36
2.6	103	96	90	85	79	74	70	65	61	58	54	51	48	46	44	42	41	40	39	39	39	39	39	39
2.7	110	103	97	91	86	80	75	71	67	63	59	56	53	50	48	46	44	43	42	41	41	41	41	41
2.8	118	111	104	98	92	87	82	77	72	68	64	61	57	54	52	50	48	46	45	44	43	43	43	43
2.9	125	118	112	105	99	93	88	83	78	74	69	66	62	59	56	54	52	50	48	47	46	46	46	46
3.0	134	126	119	113	106	100	94	89	84	79	75	71	67	64	61	58	56	54	52	50	49	49	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in completed terrace, measured from completed channel bottom to top of terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 4 of 8)

5% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

c d	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	6	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	8	7	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	10	9	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	12	11	9	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	14	13	11	10	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	17	15	14	12	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	20	18	16	15	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	23	21	19	17	16	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	26	24	21	20	18	17	16	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	29	27	24	22	21	19	18	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	33	30	28	25	23	22	20	19	18	18	17	17	17	17	17	17	17	17	17	17	17	17
1.6	37	34	31	29	26	24	23	21	20	20	19	19	19	19	19	19	19	19	19	19	19	19
1.7	41	38	35	32	30	27	26	24	23	22	21	21	21	21	21	21	21	21	21	21	21	21
1.8	45	42	38	36	33	31	29	27	25	24	23	23	22	22	22	22	22	22	22	22	22	22
1.9	49	46	42	39	37	34	32	30	28	27	26	25	24	24	24	24	24	24	24	24	24	24
2.0	54	50	47	43	40	38	35	33	31	30	28	27	27	26	26	26	26	26	26	26	26	26
2.1	59	55	51	48	44	41	39	36	34	33	31	30	29	28	28	28	28	28	28	28	28	28
2.2	64	60	56	52	49	45	43	40	38	36	34	33	32	31	30	30	30	30	30	30	30	30
2.3	69	65	60	57	53	50	47	44	41	39	37	36	34	33	33	32	32	32	32	32	32	32
2.4	74	70	65	61	58	54	51	48	45	43	41	39	37	36	35	35	34	34	34	34	34	34
2.5	80	75	71	66	62	59	55	52	49	47	44	42	41	39	38	37	37	36	36	36	36	36
2.6	86	81	76	72	67	63	60	56	53	51	48	46	44	42	41	40	39	39	39	39	39	39
2.7	92	87	82	77	73	68	65	61	58	55	52	50	48	46	44	43	42	41	41	41	41	41
2.8	98	93	87	83	78	74	70	66	62	59	56	54	51	49	48	46	45	44	44	43	43	43
2.9	104	99	93	88	84	79	75	71	67	64	61	58	55	53	51	50	48	47	46	46	46	46
3.0	111	105	100	94	89	85	80	76	72	69	65	62	60	57	55	53	52	50	49	49	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in completed terrace, measured from completed channel bottom to top of terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

S,L-24728.8

Exhibit 8-3 Terrace storage table

(sheet 5 of 8)

6% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

c d	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	6	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	7	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	9	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	11	10	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	13	12	11	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	15	14	13	12	11	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	18	16	15	14	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11
1.2	20	19	17	16	15	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	23	21	19	18	17	16	15	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1.4	26	24	22	20	19	18	17	16	16	16	16	16	16	16	16	16	16	16	16	16	16
1.5	29	27	25	23	21	20	19	18	18	17	17	17	17	17	17	17	17	17	17	17	17
1.6	33	30	28	26	24	23	21	20	20	19	19	19	19	19	19	19	19	19	19	19	19
1.7	36	33	31	29	27	25	24	23	22	21	21	21	21	21	21	21	21	21	21	21	21
1.8	40	37	34	32	30	28	26	25	24	23	23	22	22	22	22	22	22	22	22	22	22
1.9	43	40	38	35	33	31	29	28	26	25	25	24	24	24	24	24	24	24	24	24	24
2.0	47	44	41	39	36	34	32	30	29	28	27	26	26	26	26	26	26	26	26	26	26
2.1	51	48	45	42	40	37	35	33	32	31	30	29	28	28	28	28	28	28	28	28	28
2.2	56	52	49	46	43	41	38	36	35	33	32	31	31	30	30	30	30	30	30	30	30
2.3	60	57	53	50	47	44	42	40	38	36	35	34	33	32	32	32	32	32	32	32	32
2.4	65	61	57	54	51	48	46	43	41	39	38	37	36	35	34	34	34	34	34	34	34
2.5	70	66	62	58	55	52	49	47	45	43	41	40	38	37	37	36	36	36	36	36	36
2.6	75	70	66	63	59	56	53	51	48	46	44	43	41	40	39	39	39	39	39	39	39
2.7	80	75	71	67	64	60	57	55	52	50	48	46	44	43	42	41	41	41	41	41	41
2.8	85	80	76	72	68	65	62	59	56	54	51	49	48	46	45	44	44	43	43	43	43
2.9	90	86	81	77	73	70	66	63	60	57	55	53	51	50	48	47	46	46	46	46	46
3.0	96	91	87	82	78	74	71	67	64	62	59	57	55	53	52	50	49	49	48	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.

2. d - depth of water in feet in completed terrace, measured from completed channel bottom to top of terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 6 of 8)

8% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
0.7	8	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.8	10	9	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	11	10	10	9	9	9	9	9	9	9	9	9	9	9	9	9	9
1.0	13	12	11	11	10	10	10	10	10	10	10	10	10	10	10	10	10
1.1	15	14	13	12	12	11	11	11	11	11	11	11	11	11	11	11	11
1.2	17	16	15	14	13	13	13	13	13	13	13	13	13	13	13	13	13
1.3	20	18	17	16	15	15	14	14	14	14	14	14	14	14	14	14	14
1.4	22	20	19	18	17	16	16	16	16	16	16	16	16	16	16	16	16
1.5	25	23	21	20	19	18	18	17	17	17	17	17	17	17	17	17	17
1.6	27	25	24	22	21	20	20	19	19	19	19	19	19	19	19	19	19
1.7	30	28	26	25	23	22	22	21	21	21	21	21	21	21	21	21	21
1.8	33	31	29	27	26	25	24	23	23	22	22	22	22	22	22	22	22
1.9	36	34	32	30	28	27	26	25	25	24	24	24	24	24	24	24	24
2.0	39	37	35	33	31	30	28	27	27	26	26	26	26	26	26	26	26
2.1	42	40	38	36	34	32	31	30	29	28	28	28	28	28	28	28	28
2.2	46	43	41	39	37	35	34	32	31	31	30	30	30	30	30	30	30
2.3	49	46	44	42	40	38	36	35	34	33	32	32	32	32	32	32	32
2.4	53	50	47	45	43	41	39	38	37	36	35	34	34	34	34	34	34
2.5	57	54	51	48	46	44	42	41	39	38	37	37	36	36	36	36	36
2.6	60	57	54	52	49	47	45	44	42	41	40	39	39	39	39	39	39
2.7	65	61	58	55	53	51	49	47	45	44	43	42	41	41	41	41	41
2.8	69	65	62	59	57	54	52	50	48	47	46	45	44	43	43	43	43
2.9	73	69	66	63	60	58	55	53	52	50	49	48	47	46	46	46	46
3.0	77	74	70	67	64	62	59	57	55	53	52	51	50	49	48	48	48

NOTES

1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.
2. d - depth of water in feet in completed terrace, measured from completed channel bottom to top of terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 7 of 8)

10% LAND SLOPE

Combined Natural and Excavated Storage in Cubic Feet Per Lineal Foot

d \ c	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	3.0
0.1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	2	2	2	2	2	2	2	2	2	2	2	2	2
0.4	4	3	3	3	3	3	3	3	3	3	3	3	3	3
0.5	5	4	4	4	4	4	4	4	4	4	4	4	4	4
0.6	6	6	5	5	5	5	5	5	5	5	5	5	5	5
0.7	7	7	7	6	6	6	6	6	6	6	6	6	6	6
0.8	9	8	8	8	8	8	8	8	8	8	8	8	8	8
0.9	10	10	9	9	9	9	9	9	9	9	9	9	9	9
1.0	12	11	11	10	10	10	10	10	10	10	10	10	10	10
1.1	14	13	12	12	11	11	11	11	11	11	11	11	11	11
1.2	16	15	14	13	13	13	13	13	13	13	13	13	13	13
1.3	18	16	16	15	14	14	14	14	14	14	14	14	14	14
1.4	20	18	17	17	16	16	16	16	16	16	16	16	16	16
1.5	22	20	19	18	18	17	17	17	17	17	17	17	17	17
1.6	24	23	21	20	20	19	19	19	19	19	19	19	19	19
1.7	26	25	24	22	22	21	21	21	21	21	21	21	21	21
1.8	29	27	26	25	24	23	23	22	22	22	22	22	22	22
1.9	31	30	28	27	26	25	25	24	24	24	24	24	24	24
2.0	34	32	31	29	28	27	27	26	26	26	26	26	26	26
2.1	37	35	33	32	30	29	29	28	28	28	28	28	28	28
2.2	40	38	36	34	33	32	31	30	30	30	30	30	30	30
2.3	43	40	39	37	35	34	33	33	32	32	32	32	32	32
2.4	46	43	41	40	38	37	36	35	34	34	34	34	34	34
2.5	49	46	44	42	41	39	38	37	37	36	36	36	36	36
2.6	52	50	47	45	44	42	41	40	39	39	39	39	39	39
2.7	55	53	51	48	47	45	44	43	42	41	41	41	41	41
2.8	59	56	54	52	50	48	47	45	44	44	43	43	43	43
2.9	62	60	57	55	53	51	50	48	47	46	46	46	46	46
3.0	66	63	61	58	56	54	53	51	50	49	49	48	48	48

NOTES

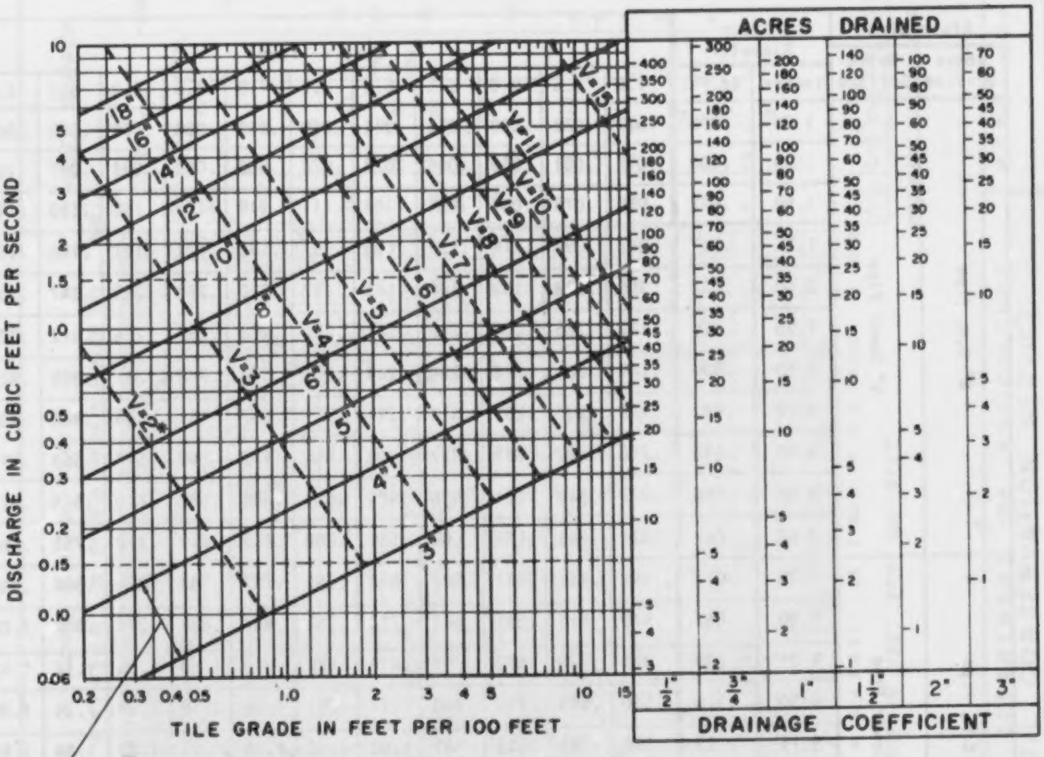
1. All frontslopes are 14 feet. Stakeline is 14 feet uphill from completed terrace ridge and will be the centerline of completed channel. c - cut in channel in feet.

2. d - depth of water in feet in completed terrace, measured from completed channel bottom to top of terrace ridge. Terrace ridge is assumed to always be at the design depth level, even when c exceeds d. Cutslope is 6:1.

Exhibit 8-3 Terrace storage table

(sheet 8 of 8)

Acres Drained by Various Sizes of Tile



Space between lines is the range of tile capacity for the size shown between lines

Reference: Yarnell - Woodward Formula $v = 138\, r^{2/3}\, s^{1/2}$ *U.S.D.A. Bulletin 854*

* *V equals velocity in feet per second*

DESIGN DATA
UNDERGROUND OUTLETS
FOR GRADED TERRACES

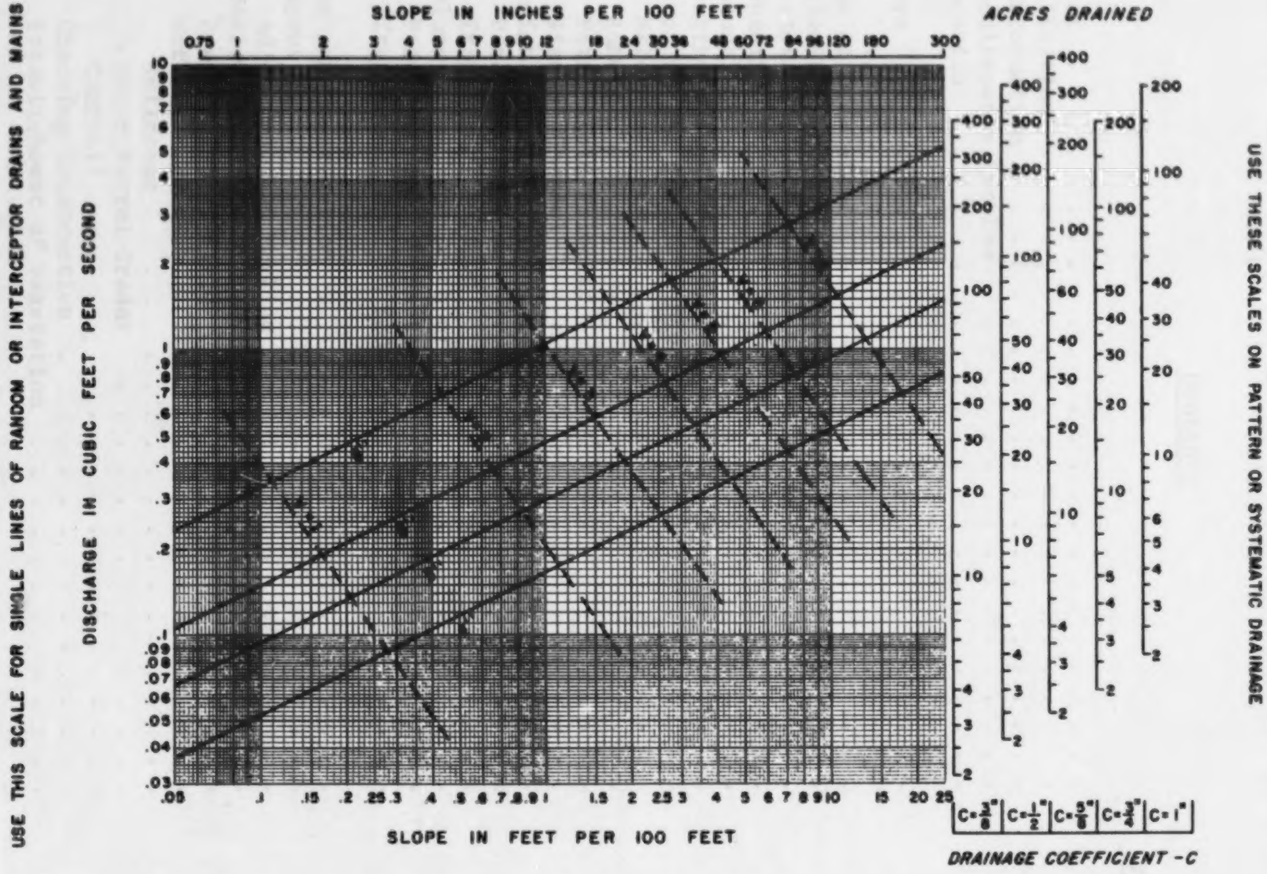
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Compiled	Checked	Date	Drawing No.
		12-65	5,0-22,438

Exhibit 8-4 Tile design chart for underground outlets

Riser Size		Orifice Diameter		Head - (feet)										
Above Orifice	Below Orifice	Inches	Sq.Ft.	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
6" C.M. Pipe	4" Sewer Pipe	1.00	.006	.027	.033	.038	.042	.046	.050	.053	.056	.059	.062	.065
		1.25	.009	.042	.051	.059	.066	.072	.078	.083	.088	.093	.097	.102
		1.50	.012	.059	.073	.084	.094	.103	.111	.119	.126	.133	.139	.146
		1.75	.017	.081	.099	.114	.128	.140	.151	.162	.172	.181	.190	.198
		2.00	.022	.105	.129	.149	.166	.182	.197	.210	.223	.235	.247	.258
		2.25	.028	.133	.163	.188	.210	.231	.249	.266	.282	.298	.312	.326
		2.50	.034	.164	.201	.232	.259	.284	.307	.328	.348	.367	.385	.402
		2.75	.041	.199	.243	.281	.314	.344	.371	.397	.421	.444	.466	.486
		3.00	.049	.236	.289	.333	.373	.408	.441	.472	.500	.527	.553	.578
		3.25	.058	.277	.339	.391	.438	.479	.518	.554	.587	.619	.649	.678
		3.50	.067	.321	.393	.454	.508	.556	.600	.642	.681	.718	.753	.786
8" C.M. Pipe	6" Sewer Pipe	3.75	.077	.369	.451	.521	.583	.638	.689	.737	.782	.824	.864	.903
		4.00	.087	.419	.513	.592	.662	.725	.783	.837	.888	.936	.982	1.03
		4.25	.099	.473	.579	.668	.747	.818	.884	.945	1.00	1.06	1.11	1.16
		4.50	.110	.530	.649	.749	.838	.917	.991	1.06	1.12	1.18	1.24	1.30
		4.75	.123	.590	.723	.835	.933	1.02	1.10	1.18	1.25	1.32	1.38	1.45
		5.00	.136	.654	.801	.925	1.03	1.13	1.22	1.31	1.39	1.46	1.53	1.60
		5.25	.150	.721	.883	1.02	1.14	1.24	1.35	1.44	1.53	1.61	1.69	1.77
		5.50	.165	.790	.968	1.12	1.25	1.37	1.48	1.58	1.68	1.77	1.85	1.94
10" C.M. Pipe	8" Sewer Pipe	5.75	.180	.863	1.06	1.22	1.37	1.50	1.62	1.72	1.83	1.93	2.02	2.11
		6.00	.196	.940	1.15	1.33	1.49	1.63	1.76	1.88	1.99	2.10	2.20	2.30

Exhibit 8-5 Discharge rates of circular orifice in c.f.s.



REFERENCE
DISCHARGE BASED ON:
$V = 99R^{2/3}S^{1/2}$
PIPE FLOWING FULL, MANNING N = 0.015

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING & WATERSHED PLANNING UNIT
UPPER DARBY, PENNSYLVANIA

RTSC - NE - ENG.
1442
SHEET 1 OF 1

EXHIBIT 8-6 DRAIN CHART - CORRUGATED PLASTIC DRAIN TUBING

ENGINEERING FIELD MANUAL

CHAPTER 9. DIVERSIONS

Compiled by: Harold M. Kautz, Agricultural Engineer, SCS, Upper Darby, Pa.

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ENGINEERING FIELD MANUAL

CHAPTER 9. DIVERSIONS

1. GENERAL

DEFINITION

A diversion is an individually-designed graded channel with a supporting ridge on the lower side, constructed across the slope.

INTRODUCTION

Diversions are used for one or more of the following purposes:

1. **To divert water away from active gully heads in order to stop erosion.**
2. **To reduce the length of slopes to supplement erosion-resistant crops or contour stripcropping on land continuously managed in crop strips.**
3. **To break up concentrations of water on long, gentle slopes and on undulating or warped land surfaces generally considered too flat or irregular for terracing.**
4. **To divert water away from farm buildings and other improvements.**
5. **To collect or direct water for water-spreading systems.**
6. **To increase or decrease the drainage area above farm ponds.**
7. **To protect terrace systems by diverting headwater from the top terrace where topography or landownership prevents terracing the land above.**
8. **To intercept sidehill surface or subsurface flow.**
9. **To protect flatlands from sidehill runoff.**
10. **To protect lowlands subject to flood or sediment damage by diverting floodflows from small side tributaries.**

REQUIREMENTS FOR USE

1. **Any high sediment-producing area above a diversion should be controlled by good land use management or by structural measures to prevent damaging sediment accumulation in the diversion channel.**

2. Where it is not possible to establish good permanent vegetation, the channel capacity must be increased to provide for sediment storage, and other sediment reduction measures should be employed wherever possible.

3. Diversions must not be substituted for terraces on land requiring terraces for erosion control.

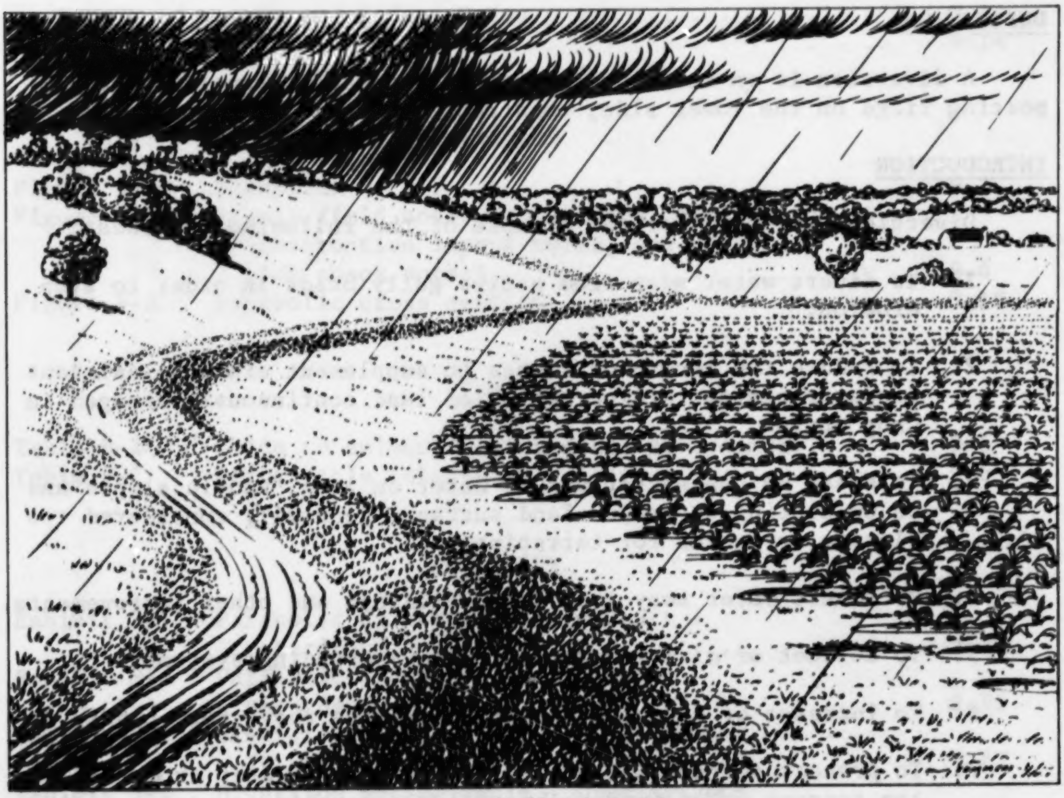


Figure 9-1 Diversion

LOCATION

1. Diversion locations should be determined by outlet conditions, topography, land use, cultural operations, soil type, and length of slope.

2. When diversions are used to intercept shallow subsurface flows in addition to surface runoff, the location and depth of cut are based on the location and nature of the seepage outcrops. Exploratory borings usually are required to determine the location of interceptors. Refer to the State Drainage Guide or local Technical Guide for additional information.

3. When a diversion is to be constructed to protect cropland from the runoff of adjoining grassland on the same farm, it should be built close to the boundary between grassland and cropland.

The area occupied by the diversion and above should be established in grass if it is not already in grass. If field terraces will be located immediately below the diversion and empty in the same direction, the diversion should be planned and staked to provide parallel rows using normal terrace gradient whenever possible. The gradient will facilitate farming operations by providing a more uniform interval between the diversion and the first terrace. Often the diversion location will necessitate relocating a fence and changing a field boundary.

There are several advantages in favor of arranging a field boundary along or near the lower edge of the diversion.

a. Grass can normally be established and maintained.

b. The diversion area can be utilized for grazing or hay, whereas it may not be utilized if it is in cropland.

c. Weeds and other objectionable vegetation on the diversion may be controlled by grazing or mowing.

4. When diverting water away from the head of a gully, it is important that the diversion be located far enough above the gully overfall so that stable slopes will exist after bank sloping and expected sloughing has taken place.

5. Diversions should be located so that water will empty on established disposal areas, natural outlets, or prepared individual outlets.

6. When diversions are used to protect bottom land from sidehill runoff, they should be located at or near the base of the upland slope to divert the water before it can spread over the flat bottom land.

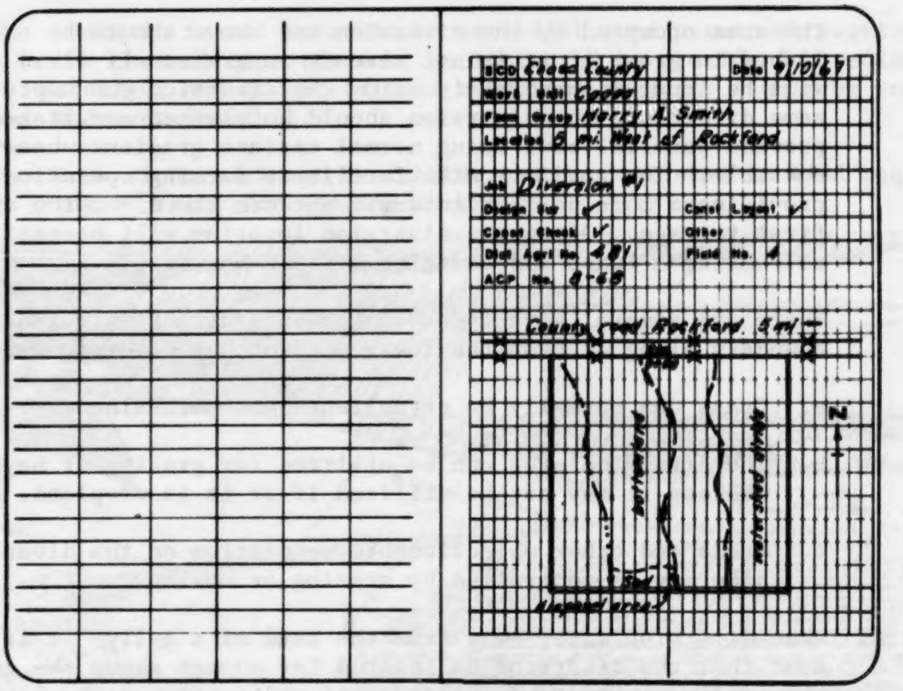
7. Floodwater diversions normally are located on the bottom land below the base of the upland slope to provide greater capacity and more economical construction.

8. When diverting water across irregular slopes, the diversion ridge should be reinforced where it crosses draws.

2. SURVEYS

Sample field notes for diversion design, layout, and construction are shown in Figure 9-2. Such notes are satisfactory when drainage areas are small, topography is relatively uniform, and elevations with respect to other structures are not important. The plotting of construction check notes is necessary because it readily points out any failures to meet design requirements.

Standard Forms or data sheets approved by the State also may be used to record field notes for diversions.



SCD Creed County Date 9/10/67

Work Unit Cooper

Farm Group Harry A. Smith

Located 5 mi. West of Rockford

Job Diversion #1

Design Sur ✓ Const Layout ✓

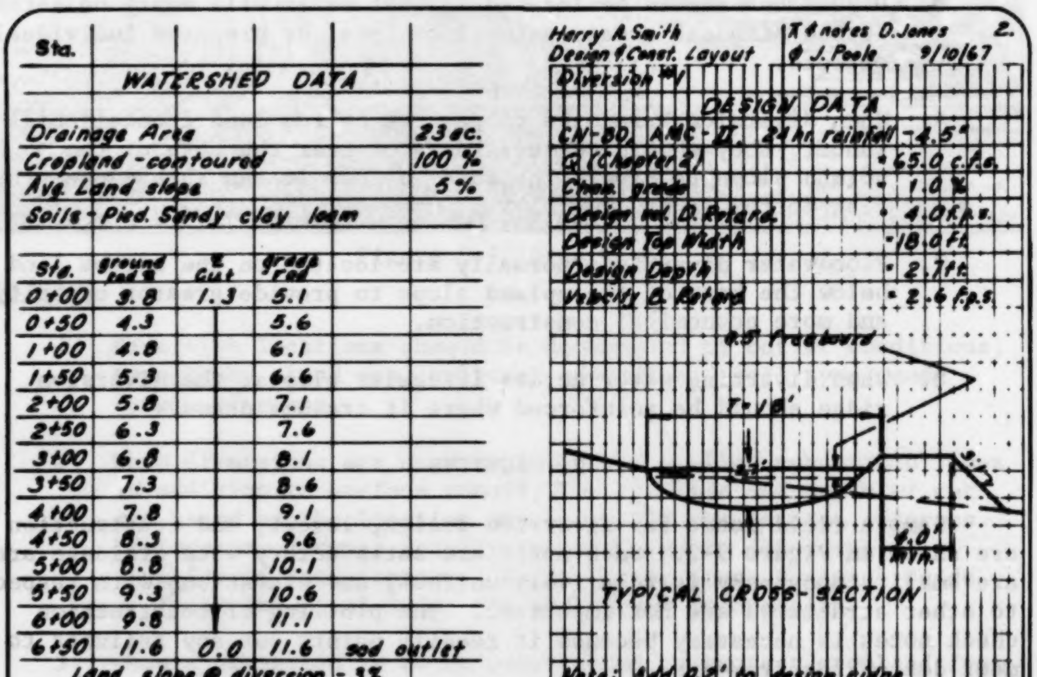
Const Check ✓ Other

Dist Agrl No. 481 Field No. 4

ACP No. 8-65

County road Rockford 5 mi →
bottomland
Rough pasture
N
Sod
Mapped area

Figure 9-2 Sample field notes - title page (sheet 1 of 3)



Sta.					
	WATERSHED DATA				
Drainage Area					23 ac.
Cropland - contoured					100 %
Avg. Land slope					5 %
Soils - Pied. Sandy clay loam					
Sta.	ground rod ℄	℄ Cut	grade rod		
0+00	3.8	1.3	5.1		
0+50	4.3		5.6		
1+00	4.8		6.1		
1+50	5.3		6.6		
2+00	5.8		7.1		
2+50	6.3		7.6		
3+00	6.8		8.1		
3+50	7.3		8.6		
4+00	7.8		9.1		
4+50	8.3		9.6		
5+00	8.8		10.1		
5+50	9.3		10.6		
6+00	9.8		11.1		
6+50	11.6	0.0	11.6	sod outlet	
Land slope @ diversion - 3%					

Harry A. Smith
Design & Const. Layout

X & notes D. Jones
& J. Poole 9/10/67 2.

Diversion #1

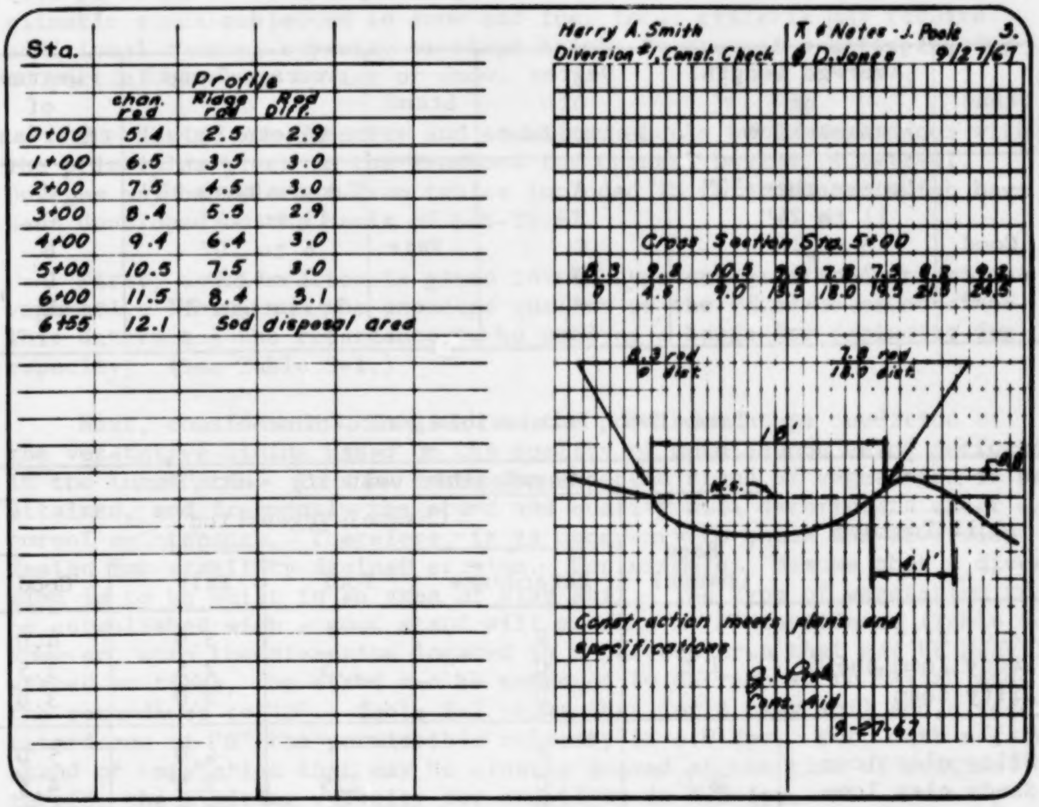
DESIGN DATA

CN-80, AMC-II, 24 hr. rainfall - 4.5"
Q (Chapter 2) = 65.0 c.f.s.
Chan. grade = 1.0 %
Design vel. @ Retard. = 4.0 f.p.s.
Design Top Width = 18.0 Ft.
Design Depth = 2.7 ft.
Velocity @ Retard = 2.6 f.p.s.

TYPICAL CROSS-SECTION

Note: Add 0.2' to design ridge height for settlement

Figure 9-2 Sample field notes - design and layout (sheet 2 of 3)



Sta.	Profile chan. rod	Ridge rod	Rod Diff.
0+00	5.4	2.5	2.9
1+00	6.5	3.5	3.0
2+00	7.5	4.5	3.0
3+00	8.4	5.5	2.9
4+00	9.4	6.4	3.0
5+00	10.5	7.5	3.0
6+00	11.5	8.4	3.1
6+55	12.1	Sod disposal area	

Harry A. Smith
Diversion #1, Const. Check

⊼ & Notes - J. Poole
& D. Jones

3.
9/27/67

Cross Section Sta. 5+00

8.3	9.8	10.5	7.9	7.8	7.5	8.2	9.2
0	4.6	9.0	13.5	18.0	19.5	21.5	24.5

8.3 rod
0 dist.
7.8 rod
18.0 dist.
15'
W.S.
0.8'
4.1'

Construction meets plans and specifications

J. Poole
Const. Aid
9-27-67

Figure 9-2 Sample field notes - construction check (sheet 3 of 3)

3. DESIGN OF DIVERSIONS

VELOCITIES

Diversions should be tailored to fit the conditions of a particular field and local soil type(s). The velocities should be kept as high as will be safe for the planned type of cover and the expected maintenance. Where permissible design velocities are not established in State Standards and Specifications, Tables 9-1 and 9-2 may be used as a guide in selecting design velocities, except in arid areas. Based on field experience, local problem soils may require other limiting velocities. The permissible velocity should be selected on the basis of the soil horizon into which the channel is excavated. For more detailed information on the effect of vegetation on retardance, see Chapter 7, Table 7-1.

Table 9-1 Guide to selection of vegetal retardance

Stand	Average length of vegetation	Degree of retardance	Stand	Average length of vegetation	Degree of retardance
Good	Longer than 30"	A	Fair	Longer than 30"	B
	11 to 24"	B		11 to 24"	C
	6 to 10"	C		6 to 10"	D
	2 to 6"	D		2 to 6"	D
	Less than 2"	E		Less than 2"	E

Table 9-2 Permissible velocities

Soil Texture	Permissible velocity - Ft./Sec.				
		Channel Vegetation			
	Bare Channel	Retardance	Poor	Fair	Good
Sand, silt, Sandy loam and Silty loam	1.5	B	1.5	3.0	4.0
		C		2.5	3.5
		D		2.0	3.0
Silty clay loam Sandy clay loam	2.0	B	2.5	4.0	5.0
		C		3.5	4.5
		D		3.0	4.0
Clay	2.5	B	3.0	5.0	6.0
		C		4.5	5.5
		D		4.0	5.0

GRADES

Grades should be selected to meet velocity and capacity requirements for the site and the section to be used. Variable grades may be needed to obtain more uniform cross sections and best possible alignment. Refer to applicable State Standards and Specifications for recommended diversion grades and conditions under which they are applicable.

CAPACITY

Diversions protecting agricultural land should have the capacity to carry at least the peak runoff from the contributing watershed for a 10-year frequency storm. Diversions designed to protect buildings and roads, and those designed to function in connection with other structures should have sufficient capacity to carry the peak runoff expected from a storm frequency consistent with the hazard involved. In addition, the constructed cross section should provide for freeboard and settlement allowances as required in State Standards and Specifications. Runoff will be computed by the method given in Chapter 2 of this manual. In climatic zones subjected to snow and ice, local criteria may require additional channel capacity or ridge height to prevent overtopping due to partial blockage by ice or snow.

The design for capacity and stability should be in accordance with the principles given in the Handbook for Channel Design, SCS-TP-61. Designs may be selected from tables included in this chapter which have been developed on the basis of SCS-TP-61.

First, consideration is given to the type and growth habits of the vegetative lining and the expected quality of the stand to be obtained. This determines the retardance to be used as a basis for designing for capacity. (See Table 9-1.)

Next, consideration is given to the possible future condition of the vegetative lining based on the quality of maintenance being performed in the local area. In some cases the expected stand of vegetation is not attained, and frequently the stand and quality will deteriorate under normal maintenance. Therefore, it is necessary to check the diversion design for stability against erosion. For example: Assume that a diversion is to be built in an area of clay soil. The type of vegetation to be established with a good stand will produce a "B" retardance (Table 9-1.) However, with the diversion located in a pasture area that may be heavily grazed at times, the stand can be expected to be reduced to "Fair" and the retardance to "D". Table 9-2 shows that for a clay soil and a vegetal retardance of "B" the permissible velocity is 6.0 fps. But, with a fair stand of vegetation that may be closely grazed at the time of critical runoff, the limiting velocity for stability is 4.0 fps.

On sites where it is impossible to establish suitable permanent vegetation, or it is desired to determine the stability of the channel in the as-constructed condition, the design should be based on bare ground conditions.

CHANNEL CROSS SECTION

It is important that channel dimensions be adapted for the farm equipment that will be used. Diversions which are easy to mow or farm also will be easier to maintain and be more acceptable to the farmer.

LENGTH

The length of diversions often is fixed by the availability of good outlets. Maximum length of diversions draining in one direction should be in accordance with State Technical Guides. In areas where prolonged flow may exist because of snowmelt, or other conditions, the length should be reduced to prevent excessive channel scour or excessive seepage that would damage lower lying land. Consideration always should be given to outletting diversions at both ends, thus dividing the flow, which may eliminate or reduce outlet problems.

STEPS IN THE DESIGN OF DIVERSIONS

Watershed Area

Determine the watershed area at the outlet of the diversion and at such other points where it may be desirable to change the grade or the cross section.

Runoff

Obtain the maximum runoff in cubic feet per second, at each design point, for the frequency storm selected. Refer to Chapter 2 of this manual for procedure.

Permissible Velocity

From Table 9-2 or the State Standards and Specifications, select the permissible velocity for the conditions encountered. For some sites and soil types, it may be necessary to design the diversion based on bare channel velocities.

Size of Channel

After "Q" and the safe velocity have been determined, the required size of diversion channel can be determined from Exhibits 9-1 to 9-4, depending on the shape of channel desired. These exhibits have been so designed that the planner has a choice of several different channel dimensions and gradients that will take care of the same quantity of flow.

Land slope must be taken into consideration when choosing channel dimensions. On the steeper slopes, narrow and deep channels may be required. On the more gentle slopes broad, shallow channels usually are applicable. The wide, shallow section will be more farmable.

In selecting the channel shape and size, the type of equipment available for construction should be considered. For example, it is quite simple for a bulldozer to shape a parabolic channel. To the extent possible, heavy construction equipment should be used for diversion construction.

DESIGN EXAMPLES

Parabolic Section

Under the subheading Capacity, page 9-6, assumptions of vegetation, soils, and maintenance were followed through tables 9-1 and 9-2, resulting in the finding that:

1. The design of the diversion capacity would be based on "B" retardance.

2. For stability the velocity in the diversion channel would be based on "D" retardance, and it should not exceed 4.0 fps.

To continue this example, assume:

1. Channel grade = 1.0 percent
2. Q (from Chapter 2) = 65 cfs

Turn to Exhibit 9-1, Sheet 4, Parabolic Diversion Design Chart, for Grade = 1.0 percent.

Since the "D" retardance limits velocity to 4.0 fps, find $V_1 = 4.0$ in the heading of the chart.

Follow down this column to the horizontal line for Q = 65, and read

T (Top width) = 18 feet
D (Depth) = 2.7 feet
V_2 (For "B" retardance) = 2.6 fps

Such a diversion, then, would have sufficient capacity to carry 65 cfs under retardance "B" conditions, and the velocity would not exceed 4.0 fps for "D" retardance.

The dimensions obtained from Exhibits 9-1 and 9-2 are for as-constructed conditions. Both T and D have been adjusted to include freeboard, but an allowance for settlement of the ridge has not been included.

By moving horizontally to the left of the column $V_1 = 4.0$ on the same chart it will be noted that there are several other diversion designs based on "D" retardance that will carry 65 cfs at velocities less than 4.0 fps.

Trapezoidal Section

With the maximum rate of runoff determined as prescribed in Chapter 2, the required size of the diversion can be found directly by using Exhibits 9-3 or 9-4. The choice of retardance "C" or "D" will depend upon the vegetation planned for the diversion channel. "D" retardance is for well maintained channels. "C" retardance is for channels with enough vegetation to cause a considerable resistance to the flow. The Handbook for Channel Design, SCS-TP-61, or similar information in the Work Unit Technical Guide, should be used in selecting the vegetal retardance.

To use the Diversion Design Table, determine the runoff "Q" as prescribed in Chapter 2. Select a bottom width to fit the method of construction and a grade to suit the field conditions. Directly under the bottom width and grade and in line with "Q" read the depth of flow and cross-sectional area of the channel required. If the design is undesirable, choose another bottom width or grade.

Given: 80 cfs is to be handled by a diversion on clay land with a

3 percent slope. It is to be constructed in bermudagrass pastureland with a bulldozer. A grade of 0.3/100 feet best suits field conditions.

Solution: Vegetal retardance "D" is chosen. The bulldozer can best construct 4:1 side slopes with a 10-foot bottom. Enter Exhibit 9-3, 4:1 side slopes, on the 80 cfs line.

Read across to the 10-foot bottom width and 0.3 grade column. The diversion requires a 2.0-foot depth of flow and a 36-square foot capacity. Add 0.5 foot for freeboard, making an overall ridge height of 2.5.

The velocity of flow = $\frac{Q}{A} = \frac{80}{36}$ or 2.2 fps. This is a safe velocity for clay soils even under poor cover. (See Table 9-2)

VOLUME, AREA, AND DEPTH OF CUT

Parabolic and "V" Sections

In some instances, it may be necessary to estimate the amount of earth moved in constructing the diversion. Exhibit 9-5 gives cubic yards per 100 linear feet for the more common sizes of "V" and parabolic diversion channels. To use the tables it is necessary to determine the land slope at the location being checked. This is done by taking a cross section between points "a" and "g" (Figure 9-3), and plotting the location of points "a", "b", "d", "e", "f", and "g". Draw lines "ab", "bd", "de", "ef", and "fg" to show the constructed section. Then draw dashed line "bf" which will represent the natural undisturbed ground slope. The intersection of line "bf" with line "de" gives point "h". The distance between points "b" and "h" may be scaled to give the width of excavation "L". The cut depth "c" may be scaled from the sketch also.

Example: To find the cubic yards of excavation for a diversion with a parabolic cross section. After plotting the cross section, the following values are scaled from the drawings:

Width of excavation L = 13.0'
Depth of cut c = 1.2'

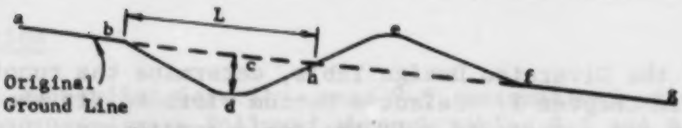


Figure 9-3 Parabolic cross section

From Exhibit 9-5, read 38.5 cubic yards per 100 feet of length. This figure is an estimate of the earth moved during construction. The accuracy of the estimate will depend on the selection of the section checked. It should represent the average conditions for the reach being calculated.

Trapezoidal and "V" Sections

Exhibit 9-6, Centerline Depth of Cut and Area of Excavation, is to be used only with Exhibits 9-3 and 9-4. Continuing with the trapezoidal design example, Exhibit 9-6: In the 3 percent slope group and on the 2.5 height line read across to the 10-foot bottom width block. In the 4:1 side slope column read 1.2 depth of excavation and 18.1 square feet of excavation. The channel excavation will build the required ridge. The area of excavation can be converted to cubic yards per 100 feet of diversion by multiplying the area by 100 and dividing by 27.

4. LAYOUT AND CONSTRUCTION

LAYOUT

Use the same general procedure in laying out diversions as is used in terraces. Where two or more diversions are to be constructed in one field, they should be staked parallel or to the best alignment that can be obtained in order to eliminate or reduce point rows.

The layout of the diversion should begin at the key point. Usually this is the outlet, but it may be a point determined by a farm building, property boundary, or a gully. On smooth, uniform slopes the stakes may be set 100 feet apart, but on abrupt changes in slope stakes may need to be set closer than 100 feet.

When the diversion spills onto grassland or a broad, shallow waterway, allowance must be made for the depth of channel cut plus gradient in the last 50 or 100 feet in order to outlet the water at ground level.

Adjustment and Marking

After the line has been staked, it is well to check and move some stakes, if necessary, to ease sharp turns and to give the best possible alignment. Ordinarily, such adjustments are limited to about 6 inches of extra cut or fill. The staked line then should be marked with a plow or other means to make a continuous furrow. A much better line will be marked if the technician will walk in front of the plow, pulling the stakes as he goes.

CONSTRUCTION

Preparation of Field

The best time to build diversions is when the watershed area is mainly in grass or other good cover so that runoff and silting will be at a minimum. All dead furrows, ditches, or gullies that are to be

crossed should be filled and compacted before construction begins so as to prevent seepage through the ridge, prevent more than normal settlement, and facilitate construction. All fills should be full-bodied. All old fence rows should be leveled. Any vegetation which would interfere with constructing a dense fill should be removed. Heavy sod should be thoroughly disked.

Methods

Heavy construction equipment should be used for the construction of diversions. Construction usually should be done from the upper side of the ridge, using the staked line as the centerline of the diversion channel. However, where good grass cover exists it may be desirable to construct the diversion from the lower side to retain existing cover in the channel.

Bulldozer

The bulldozer has several advantages in diversion construction. It can be used on very rough, stony, or eroded soils. Old dead furrows and existing ditches can be filled as part of the diversion construction operation. The bulldozer will operate under conditions where other types of equipment cannot function efficiently, such as in extremely dry soils. Two methods have been commonly used (Exhibit 9-7). The area under the ridge should be stripped of sod or disked as required, before starting construction to obtain a good bond between the ridge and natural ground. The roughing-in is accomplished by making three or more "cuts" and "bucks" at right angles to the ridge depending on the size of ridge required. See Exhibit 9-7. After the roughing-in is completed, two rounds or more are made lengthwise to shape the front and back slopes. Sometimes one round is made in the channel to give the diversion its final shape and cross section.

Motor Patrol Grader

For light or medium work, where earth is not to be transported, this type of equipment does an excellent job. A skilled operator can cut a channel true to grade, and very little followup will be required to remove high and low spots in the channel. (See Exhibit 9-8 for a suggested sequence of trips.)

Carryall

The use of this type of equipment is desirable when it is necessary to transport earth some distance from cut to fill areas. It works well in combination with either the bulldozer or grader.

Checking Construction

When construction has been completed, the diversion should be checked carefully for compliance with design and layout while the equipment still is available to make necessary changes. The finished grade and ridge height should be checked throughout the length of the diversion and the cross-sectional area of the channel should be checked at the location least likely to meet the design.

Establishment of Vegetation

If vegetation is needed in the diversion channel to protect it from erosion, it should be established as soon after construction as weather conditions permit. Even for diversions with low-designed velocities in grassland it is well to establish desirable vegetation on the ridge and channel to retard undesirable plant growth.

5. OUTLETS

The runoff collected and discharged by a diversion must be conveyed to a point of safe disposal. An adequate vegetated or underground outlet should be available or established before the diversion is constructed. (See Chapter 7 for vegetated outlets and Chapter 8 for underground outlets.)

6. MAINTENANCE

VEGETATED CHANNEL AND FRONT SLOPE

The success or failure of a properly designed and constructed diversion depends on two things: the outlet, and proper maintenance. In case the diversion is constructed at a time when a permanent seeding cannot be made, a temporary cover crop seeding is recommended. The vegetation on the diversion and filter strip should receive regular treatments of fertilizer to maintain good growth, if required by local Technical Guides. It is important that the channel of a diversion used for intercepting seepage flow be maintained in short vegetative growth or kept bare, in accordance with the design, to prevent retardation of flow and discourage seepage through the ridge.

ANNUAL CARE OF VEGETATION

Mowing, spraying, or limited grazing of the diversion channel is essential to prevent tall grass, weeds, briars, and brushy growth from obstructing flow. Such growth generally occurs where diversions are emptied into wooded areas. When woody growth gets too large, mowing becomes impossible and the diversion channel gradually becomes clogged. Diversions clogged with tall grass and brush encourage channel blockage and may cause seepage through the ridge, which may result in failure.

REMOVAL OF SEDIMENT

The channel may require spot maintenance to remove small sediment deposits. However, if the deposit extends over long reaches or for the full length of the diversion, the channel should be plowed out or reworked by use of appropriate construction equipment.

REPAIR OF BREAKS AND RODENT HOLES

Diversions left in permanent vegetation sometimes attract rodents and other burrowing animals. The ridge should be examined frequently

and if any breaks or holes are observed, they should be repaired, using earth taken just below the toe of the ridge.

SEEDING

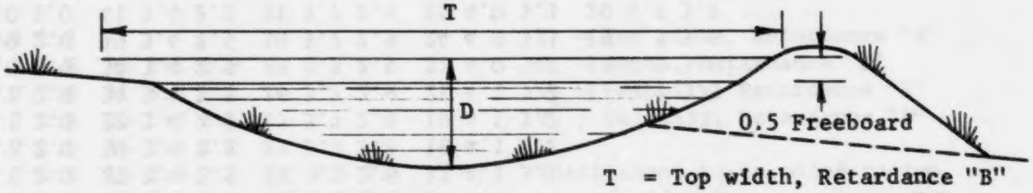
All plowing and farming operations should be parallel to the centerline of the channel when reseeding the diversion. Plowing should be done by backfurrowing to the ridge to produce a dead furrow in the channel. This method of plowing will maintain the ridge height required in the original design. Seeding preferably should be done when the strip immediately above the diversion is in hay or other solid cover.

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B"

Grade = 0.25%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	12	3.8	1.0																								
30	14	3.6	1.1																								
35	17	3.5	1.1																								
40	19	3.5	1.2	13	4.1	1.4																					
45	21	3.4	1.2	14	4.0	1.4																					
50	23	3.4	1.2	16	3.9	1.5																					
55	26	3.4	1.2	17	3.9	1.5																					
60	28	3.4	1.2	19	3.9	1.5																					
65	30	3.4	1.2	20	3.8	1.6																					
70	32	3.4	1.2	22	3.8	1.6	15	4.5	1.8																		
75	34	3.4	1.2	23	3.8	1.6	16	4.4	1.9																		
80	37	3.4	1.2	25	3.8	1.6	17	4.4	1.9																		
90	41	3.4	1.2	28	3.8	1.6	19	4.3	1.9																		
100	46	3.4	1.2	31	3.7	1.6	21	4.3	2.0																		
110	50	3.4	1.2	34	3.7	1.6	23	4.2	2.0																		
120	55	3.4	1.3	37	3.7	1.6	26	4.2	2.0	18	5.0	2.3															
130	59	3.4	1.3	40	3.7	1.6	28	4.2	2.0	19	4.9	2.4															
140	64	3.3	1.3	43	3.7	1.7	30	4.2	2.0	21	4.9	2.4															
150	68	3.3	1.3	46	3.7	1.7	32	4.2	2.0	22	4.8	2.5															
160	73	3.3	1.3	49	3.7	1.7	34	4.2	2.0	24	4.8	2.5															
170	77	3.3	1.3	52	3.7	1.7	36	4.2	2.1	25	4.8	2.5	20	5.5	2.8												
180	82	3.3	1.3	55	3.7	1.7	38	4.2	2.1	26	4.7	2.6	21	5.4	2.8												
190	86	3.3	1.3	58	3.7	1.7	40	4.2	2.1	28	4.7	2.6	22	5.4	2.8												
200	91	3.3	1.3	61	3.7	1.7	42	4.2	2.1	29	4.7	2.6	23	5.3	2.9												
220				67	3.7	1.7	46	4.2	2.1	32	4.7	2.6	25	5.3	2.9												
240				73	3.7	1.7	50	4.1	2.1	35	4.7	2.6	27	5.2	3.0												
260				79	3.7	1.7	54	4.1	2.1	38	4.7	2.6	29	5.2	3.0	22	6.0	3.3									
280				85	3.7	1.7	59	4.1	2.1	40	4.6	2.6	31	5.1	3.1	24	5.9	3.4									
300				91	3.7	1.7	63	4.1	2.1	43	4.6	2.7	33	5.1	3.1	26	5.9	3.4									



T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 1 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B" Grade = 0.5%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	12	2.8	1.0																								
20	15	2.7	1.0																								
25	18	2.7	1.1	12	3.1	1.4																					
30	22	2.6	1.1	14	3.0	1.4	10	3.4	1.6																		
35	25	2.6	1.1	16	3.0	1.5	12	3.3	1.7																		
40	29	2.6	1.1	18	2.9	1.5	13	3.2	1.8																		
45	33	2.6	1.1	20	2.9	1.5	15	3.2	1.8																		
50	36	2.6	1.1	22	2.9	1.5	17	3.1	1.9	12	3.7	2.1															
55	40	2.6	1.1	24	2.9	1.6	18	3.1	1.9	13	3.6	2.2															
60	43	2.6	1.1	27	2.9	1.6	20	3.1	1.9	14	3.6	2.2															
65	47	2.6	1.1	29	2.9	1.6	21	3.1	1.9	15	3.5	2.3															
70	50	2.6	1.1	31	2.9	1.6	23	3.1	1.9	16	3.5	2.3															
75	54	2.6	1.1	33	2.9	1.6	25	3.1	1.9	17	3.5	2.3	14	4.0	2.5												
80	58	2.6	1.1	35	2.9	1.6	26	3.1	1.9	18	3.5	2.4	15	3.9	2.6												
90	65	2.6	1.1	40	2.9	1.6	29	3.1	2.0	21	3.5	2.4	16	3.9	2.6												
100	72	2.6	1.1	44	2.8	1.6	32	3.1	2.0	23	3.4	2.4	18	3.8	2.7	14	4.3	3.0									
110	79	2.6	1.1	48	2.8	1.6	36	3.1	2.0	25	3.4	2.4	20	3.8	2.8	16	4.2	3.1									
120	86	2.6	1.1	52	2.8	1.6	39	3.1	2.0	27	3.4	2.5	21	3.7	2.8	17	4.1	3.1									
130	93	2.6	1.1	57	2.8	1.6	42	3.1	2.0	30	3.4	2.5	23	3.7	2.8	18	4.1	3.2									
140				61	2.8	1.6	45	3.1	2.0	32	3.4	2.5	25	3.7	2.8	19	4.1	3.2									
150				65	2.8	1.6	48	3.1	2.0	34	3.4	2.5	26	3.7	2.9	21	4.1	3.2	17	4.6	3.5						
160				70	2.8	1.6	52	3.0	2.0	36	3.4	2.5	28	3.7	2.9	22	4.0	3.3	18	4.5	3.6						
170				74	2.8	1.6	55	3.0	2.0	39	3.4	2.5	30	3.7	2.9	24	4.0	3.3	19	4.5	3.6						
180				78	2.8	1.6	58	3.0	2.0	41	3.4	2.5	31	3.7	2.9	25	4.0	3.3	20	4.5	3.7						
190				83	2.8	1.6	61	3.0	2.0	43	3.4	2.5	33	3.7	2.9	26	4.0	3.3	21	4.5	3.7						
200				87	2.8	1.6	64	3.0	2.0	45	3.4	2.5	35	3.7	2.9	27	4.0	3.3	22	4.4	3.8	18	5.0	4.0			
220				95	2.8	1.6	71	3.0	2.0	50	3.4	2.5	38	3.7	2.9	30	4.0	3.4	24	4.4	3.8	19	4.9	4.1			
240							77	3.0	2.0	54	3.4	2.5	42	3.7	2.9	33	4.0	3.4	26	4.4	3.8	21	4.9	4.1			
260							83	3.0	2.0	59	3.4	2.5	45	3.7	3.0	36	4.0	3.4	28	4.3	3.9	23	4.8	4.2			
280							90	3.0	2.0	63	3.4	2.5	48	3.7	3.0	38	4.0	3.4	30	4.3	3.9	24	4.8	4.2	20	5.4	4.5
300							96	3.0	2.0	68	3.4	2.5	52	3.6	3.0	41	4.0	3.4	32	4.3	3.9	26	4.8	4.3	21	5.3	4.6

T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 2 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B"

Grade = 0.75%

Q	$V_1 = 2.0$			$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$			$V_1 = 4.5$			$V_1 = 5.0$			$V_1 = 5.5$			$V_1 = 6.0$		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	16	2.3	0.9	10	2.7	1.2																					
20	21	2.3	0.9	12	2.6	1.4																					
25	26	2.2	1.0	14	2.5	1.4	11	2.8	1.7																		
30	31	2.2	1.0	17	2.5	1.4	12	2.8	1.8	10	3.1	1.9															
35	36	2.2	1.0	20	2.5	1.5	14	2.7	1.8	11	3.0	2.1															
40	41	2.2	1.0	23	2.5	1.5	16	2.7	1.8	13	2.9	2.1															
45	46	2.2	1.0	26	2.5	1.5	18	2.7	1.9	14	2.9	2.2															
50	51	2.2	1.0	28	2.5	1.5	20	2.7	1.9	16	2.9	2.2	12	3.3	2.5												
55	56	2.2	1.0	31	2.5	1.5	22	2.7	1.9	17	2.9	2.2	13	3.3	2.5												
60	61	2.2	1.0	34	2.5	1.5	24	2.7	1.9	19	2.9	2.2	14	3.2	2.6												
65	66	2.2	1.0	37	2.5	1.5	26	2.6	1.9	20	2.8	2.3	15	3.2	2.6	12	3.5	2.8									
70	71	2.2	1.0	39	2.5	1.5	28	2.6	1.9	22	2.8	2.3	16	3.2	2.7	13	3.5	2.9									
75	76	2.2	1.0	42	2.5	1.5	30	2.6	1.9	23	2.8	2.3	17	3.2	2.7	14	3.5	2.9									
80	81	2.2	1.0	45	2.5	1.5	32	2.6	1.9	25	2.8	2.3	18	3.2	2.7	15	3.4	3.0									
90	91	2.2	1.0	50	2.5	1.5	36	2.6	1.9	28	2.8	2.3	20	3.1	2.8	16	3.4	3.1	13	3.8	3.3						
100				56	2.5	1.5	40	2.6	1.9	31	2.8	2.3	22	3.1	2.8	18	3.4	3.1	15	3.7	3.4						
110				61	2.5	1.5	44	2.6	1.9	34	2.8	2.3	25	3.1	2.8	20	3.3	3.2	16	3.7	3.5						
120				67	2.5	1.5	48	2.6	2.0	37	2.8	2.3	27	3.1	2.8	22	3.3	3.2	18	3.6	3.5	14	4.0	3.8			
130				72	2.5	1.5	52	2.6	2.0	40	2.8	2.3	29	3.1	2.9	23	3.3	3.2	19	3.6	3.6	16	4.0	3.8			
140				78	2.5	1.5	56	2.6	2.0	43	2.8	2.3	31	3.1	2.9	25	3.3	3.2	20	3.6	3.6	17	4.0	3.9			
150				83	2.5	1.6	60	2.6	2.0	46	2.8	2.3	33	3.1	2.9	27	3.3	3.2	22	3.6	3.7	18	3.9	4.0			
160				89	2.5	1.6	64	2.6	2.0	49	2.8	2.3	35	3.1	2.9	29	3.3	3.3	23	3.6	3.7	19	3.9	4.0	15	4.3	4.4
170				94	2.5	1.6	68	2.6	2.0	52	2.8	2.3	38	3.1	2.9	31	3.3	3.3	24	3.5	3.7	20	3.9	4.1	16	4.3	4.4
180							72	2.6	2.0	55	2.8	2.3	40	3.1	2.9	32	3.3	3.3	26	3.5	3.7	21	3.8	4.1	17	4.2	4.5
190							76	2.6	2.0	58	2.8	2.3	42	3.1	2.9	34	3.3	3.3	27	3.5	3.7	22	3.8	4.1	18	4.2	4.5
200							80	2.6	2.0	61	2.8	2.3	44	3.1	2.9	36	3.3	3.3	29	3.5	3.7	23	3.8	4.2	19	4.2	4.5
220							87	2.6	2.0	68	2.8	2.3	48	3.1	2.9	39	3.3	3.3	32	3.5	3.7	26	3.8	4.2	21	4.2	4.6
240							95	2.6	2.0	74	2.8	2.4	53	3.1	2.9	43	3.3	3.3	34	3.5	3.8	28	3.8	4.2	23	4.1	4.6
260										80	2.8	2.4	57	3.1	2.9	46	3.3	3.3	37	3.5	3.8	30	3.8	4.2	25	4.1	4.7
280										86	2.8	2.4	62	3.1	2.9	50	3.3	3.3	40	3.5	3.8	32	3.8	4.3	26	4.1	4.7
300										92	2.8	2.4	66	3.1	2.9	53	3.3	3.3	43	3.5	3.8	35	3.8	4.3	28	4.1	4.7

T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 3 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B"

Grade = 1.0%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	18	2.1	0.9	11	2.3	1.2																					
20	24	2.0	0.9	15	2.2	1.3	10	2.5	1.7																		
25	30	2.0	0.9	19	2.2	1.3	12	2.5	1.7	10	2.7	1.9															
30	36	2.0	0.9	22	2.2	1.4	15	2.4	1.8	12	2.6	2.0															
35	42	2.0	0.9	26	2.2	1.4	17	2.4	1.8	14	2.6	2.1	10	2.9	2.4												
40	48	2.0	1.0	29	2.2	1.4	19	2.4	1.8	15	2.5	2.1	12	2.8	2.5												
45	54	2.0	1.0	33	2.2	1.4	22	2.4	1.8	17	2.5	2.1	13	2.8	2.5												
50	59	2.0	1.0	37	2.2	1.4	24	2.4	1.9	19	2.5	2.2	14	2.8	2.5	11	3.1	2.9									
55	65	2.0	1.0	40	2.2	1.4	26	2.4	1.9	21	2.5	2.2	16	2.8	2.6	12	3.1	2.9									
60	71	2.0	1.0	44	2.2	1.4	29	2.4	1.9	23	2.5	2.2	17	2.7	2.6	13	3.0	3.0									
65	77	2.0	1.0	47	2.2	1.4	31	2.4	1.9	25	2.5	2.2	18	2.7	2.6	14	3.0	3.0	11	3.4	3.2						
70	83	2.0	1.0	51	2.2	1.4	33	2.4	1.9	26	2.5	2.2	20	2.7	2.6	15	3.0	3.0	12	3.3	3.3						
75	88	2.0	1.0	54	2.2	1.4	36	2.4	1.9	28	2.5	2.2	21	2.7	2.7	16	3.0	3.1	13	3.3	3.4						
80	94	2.0	1.0	58	2.2	1.4	38	2.4	1.9	30	2.5	2.2	23	2.7	2.7	17	3.0	3.1	14	3.2	3.4						
90				65	2.2	1.4	43	2.4	1.9	34	2.5	2.2	25	2.7	2.7	19	3.0	3.1	16	3.2	3.5	13	3.5	3.8			
100				72	2.2	1.4	47	2.4	1.9	38	2.5	2.2	28	2.7	2.7	21	3.0	3.1	17	3.2	3.6	14	3.4	3.9			
110				79	2.2	1.4	52	2.4	1.9	41	2.5	2.3	31	2.7	2.7	23	2.9	3.2	19	3.2	3.6	16	3.4	3.9	13	3.7	4.1
120				86	2.2	1.4	57	2.4	1.9	45	2.5	2.3	34	2.7	2.7	25	2.9	3.2	21	3.2	3.6	17	3.4	4.0	15	3.7	4.2
130				94	2.2	1.4	61	2.4	1.9	49	2.5	2.3	36	2.7	2.7	27	2.9	3.2	22	3.1	3.6	18	3.4	4.0	16	3.6	4.3
140							66	2.4	1.9	52	2.5	2.3	39	2.7	2.7	29	2.9	3.2	23	3.1	3.6	20	3.4	4.1	17	3.6	4.3
150							71	2.4	1.9	56	2.5	2.3	42	2.7	2.7	31	2.9	3.2	26	3.1	3.7	21	3.4	4.1	18	3.6	4.4
160							75	2.4	1.9	60	2.5	2.3	45	2.7	2.7	33	2.9	3.2	27	3.1	3.7	22	3.4	4.1	19	3.6	4.4
170							80	2.4	1.9	63	2.5	2.3	47	2.7	2.7	35	2.9	3.3	29	3.1	3.7	24	3.4	4.1	20	3.6	4.5
180							84	2.4	1.9	67	2.5	2.3	50	2.7	2.7	38	2.9	3.3	31	3.1	3.7	25	3.3	4.1	21	3.5	4.5
190							89	2.4	1.9	71	2.5	2.3	53	2.7	2.7	40	2.9	3.3	32	3.1	3.7	26	3.3	4.2	22	3.5	4.5
200							94	2.4	1.9	74	2.5	2.3	55	2.7	2.7	42	2.9	3.3	34	3.1	3.7	28	3.3	4.2	24	3.5	4.6
220										82	2.5	2.3	61	2.7	2.7	46	2.9	3.3	37	3.1	3.7	30	3.3	4.2	26	3.5	4.6
240										89	2.5	2.3	66	2.7	2.8	50	2.9	3.3	41	3.1	3.7	33	3.3	4.2	28	3.5	4.6
260										96	2.5	2.3	72	2.7	2.8	54	2.9	3.3	44	3.1	3.8	36	3.3	4.2	30	3.5	4.7
280													77	2.7	2.8	58	2.9	3.3	47	3.1	3.8	38	3.3	4.2	33	3.5	4.7
300													83	2.7	2.8	62	2.9	3.3	50	3.1	3.8	41	3.3	4.2	35	3.5	4.7

T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 4 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B" Grade = 1.5%

Q	$V_1 = 2.0$			$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$			$V_1 = 4.5$			$V_1 = 5.0$			$V_1 = 5.5$			$V_1 = 6.0$		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	24	1.8	0.9	15	1.9	1.2	10	2.2	1.5																		
20	32	1.8	0.9	20	1.9	1.2	14	2.1	1.6																		
25	39	1.8	0.9	25	1.9	1.2	17	2.1	1.6	11	2.3	2.1															
30	47	1.8	0.9	31	1.9	1.2	20	2.1	1.6	13	2.3	2.2	11	2.4	2.4												
35	55	1.8	0.9	36	1.9	1.2	23	2.1	1.7	16	2.2	2.2	13	2.4	2.5	10	2.6	2.7									
40	63	1.8	0.9	41	1.9	1.2	27	2.1	1.7	18	2.2	2.2	14	2.3	2.6	12	2.5	2.8									
45	70	1.8	0.9	46	1.9	1.2	30	2.1	1.7	20	2.2	2.2	16	2.3	2.6	13	2.5	2.8	10	2.8	3.2						
50	78	1.8	0.9	51	1.9	1.2	33	2.1	1.7	22	2.2	2.2	18	2.3	2.6	15	2.5	2.9	11	2.8	3.3						
55	86	1.8	0.9	55	1.9	1.2	36	2.1	1.7	24	2.2	2.3	20	2.3	2.6	16	2.5	2.9	12	2.7	3.4	10	3.0	3.5			
60	93	1.8	0.9	60	1.9	1.2	40	2.0	1.7	26	2.2	2.3	21	2.3	2.6	17	2.5	2.9	13	2.7	3.4	11	3.0	3.6			
65				65	1.9	1.2	43	2.0	1.7	29	2.2	2.3	23	2.3	2.6	19	2.5	3.0	14	2.7	3.4	12	2.9	3.7			
70				70	1.9	1.2	46	2.0	1.7	31	2.2	2.3	25	2.3	2.6	20	2.5	3.0	15	2.7	3.4	13	2.9	3.8	11	3.1	4.0
75				75	1.9	1.2	49	2.0	1.7	33	2.2	2.3	26	2.3	2.7	22	2.5	3.0	16	2.7	3.5	14	2.9	3.8	12	3.1	4.0
80				80	1.9	1.2	52	2.0	1.7	35	2.2	2.3	28	2.3	2.7	23	2.5	3.0	18	2.7	3.5	15	2.9	3.8	13	3.1	4.2
90				90	1.9	1.2	59	2.0	1.7	39	2.2	2.3	32	2.3	2.7	26	2.5	3.0	20	2.7	3.5	16	2.8	3.9	14	3.0	4.2
100							65	2.0	1.7	44	2.2	2.3	35	2.3	2.7	29	2.4	3.0	22	2.7	3.5	18	2.8	4.0	15	3.0	4.3
110							72	2.0	1.7	48	2.2	2.3	39	2.3	2.7	31	2.4	3.0	24	2.7	3.5	20	2.8	4.0	17	3.0	4.4
120							78	2.0	1.7	52	2.2	2.3	42	2.3	2.7	34	2.4	3.0	26	2.6	3.6	22	2.8	4.0	18	3.0	4.4
130							85	2.0	1.7	57	2.2	2.3	45	2.3	2.7	37	2.4	3.0	28	2.6	3.6	23	2.8	4.0	19	3.0	4.4
140							91	2.0	1.7	61	2.2	2.3	49	2.3	2.7	40	2.4	3.1	30	2.6	3.6	25	2.8	4.0	21	3.0	4.5
150							97	2.0	1.7	65	2.2	2.3	52	2.3	2.7	43	2.4	3.1	32	2.6	3.6	27	2.8	4.0	22	2.9	4.5
160										69	2.2	2.3	56	2.3	2.7	45	2.4	3.1	34	2.6	3.6	29	2.8	4.1	24	2.9	4.5
170										74	2.2	2.3	59	2.3	2.7	48	2.4	3.1	37	2.6	3.6	30	2.8	4.1	25	2.9	4.5
180										78	2.2	2.3	63	2.3	2.7	51	2.4	3.1	39	2.6	3.6	32	2.8	4.1	27	2.9	4.6
190										82	2.2	2.3	66	2.3	2.7	54	2.4	3.1	41	2.6	3.7	34	2.8	4.1	28	2.9	4.6
200										86	2.2	2.3	69	2.3	2.7	56	2.4	3.1	43	2.6	3.7	36	2.8	4.1	30	2.9	4.6
220										95	2.2	2.3	76	2.3	2.7	62	2.4	3.1	47	2.6	3.7	39	2.8	4.1	33	2.9	4.6
240													83	2.3	2.7	68	2.4	3.1	51	2.6	3.7	43	2.8	4.1	35	2.9	4.6
260													90	2.3	2.7	73	2.4	3.1	55	2.6	3.7	46	2.8	4.1	38	2.9	4.6
280													97	2.3	2.7	79	2.4	3.1	60	2.6	3.7	50	2.8	4.1	41	2.9	4.6
300																84	2.4	3.1	64	2.6	3.7	53	2.8	4.1	44	2.9	4.7

T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 5 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "B"

Grade = 2.0%

Q	$V_1 = 2.0$			$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$			$V_1 = 4.5$			$V_1 = 5.0$			$V_1 = 5.5$			$V_1 = 6.0$		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	30	1.6	0.8	18	1.8	1.2	13	1.9	1.4	9	2.1	1.8															
20	39	1.6	0.8	24	1.8	1.2	17	1.9	1.5	12	2.0	1.9															
25	49	1.6	0.8	30	1.7	1.2	21	1.9	1.5	15	2.0	2.0	11	2.2	2.4												
30	59	1.6	0.8	35	1.7	1.2	25	1.9	1.5	18	2.0	2.0	13	2.1	2.5	10	2.3	2.8									
35	68	1.6	0.8	41	1.7	1.2	29	1.9	1.5	21	2.0	2.0	15	2.1	2.5	12	2.2	2.9	10	2.4	3.0						
40	78	1.6	0.8	47	1.7	1.2	34	1.9	1.5	23	2.0	2.0	17	2.1	2.5	14	2.2	2.9	11	2.4	3.2						
45	88	1.6	0.8	53	1.7	1.2	38	1.9	1.5	26	2.0	2.0	19	2.1	2.5	15	2.2	2.9	13	2.4	3.2	10	2.6	3.5			
50	97	1.6	0.8	59	1.7	1.2	42	1.9	1.6	29	2.0	2.0	21	2.1	2.6	17	2.2	2.9	14	2.4	3.2	11	2.5	3.6			
55				64	1.7	1.2	46	1.8	1.6	32	2.0	2.0	23	2.1	2.6	19	2.2	2.9	15	2.4	3.3	12	2.5	3.7	10	2.7	4.0
60				70	1.7	1.2	50	1.8	1.6	35	2.0	2.0	25	2.1	2.6	20	2.2	3.0	17	2.4	3.3	13	2.5	3.7	11	2.7	4.0
65				76	1.7	1.2	54	1.8	1.6	38	2.0	2.0	27	2.1	2.6	22	2.2	3.0	18	2.3	3.4	15	2.5	3.7	12	2.7	4.1
70				81	1.7	1.2	58	1.8	1.6	41	2.0	2.1	29	2.1	2.6	24	2.2	3.0	19	2.3	3.4	16	2.5	3.8	13	2.7	4.1
75				87	1.7	1.2	62	1.8	1.6	43	2.0	2.1	31	2.1	2.6	25	2.2	3.0	21	2.3	3.4	17	2.5	3.8	14	2.7	4.1
80				93	1.7	1.2	68	1.8	1.6	46	2.0	2.1	33	2.1	2.6	27	2.2	3.0	22	2.3	3.4	18	2.5	3.8	15	2.6	4.2
90							74	1.8	1.6	52	2.0	2.1	37	2.1	2.6	30	2.2	3.0	25	2.3	3.4	20	2.5	3.8	17	2.6	4.2
100							83	1.8	1.6	58	2.0	2.1	41	2.1	2.6	34	2.2	3.0	27	2.3	3.4	22	2.5	3.9	18	2.6	4.3
110							91	1.8	1.6	63	2.0	2.1	45	2.1	2.6	37	2.2	3.0	30	2.3	3.4	24	2.5	3.9	20	2.6	4.3
120							99	1.8	1.6	69	2.0	2.1	49	2.1	2.6	40	2.2	3.0	33	2.3	3.4	26	2.4	3.9	22	2.6	4.3
130										75	2.0	2.1	53	2.1	2.6	44	2.2	3.0	35	2.3	3.4	29	2.4	3.9	24	2.6	4.3
140										80	2.0	2.1	57	2.1	2.6	47	2.2	3.0	38	2.3	3.5	31	2.4	3.9	26	2.6	4.4
150										86	2.0	2.1	61	2.1	2.7	50	2.2	3.0	41	2.3	3.5	33	2.4	3.9	27	2.6	4.4
160										91	2.0	2.1	65	2.1	2.7	53	2.2	3.0	43	2.3	3.5	35	2.4	3.9	29	2.6	4.4
170										97	2.0	2.1	69	2.1	2.7	57	2.2	3.1	46	2.3	3.5	37	2.4	4.0	31	2.6	4.4
180													73	2.1	2.7	60	2.2	3.1	49	2.3	3.5	39	2.4	4.0	33	2.6	4.4
190													77	2.1	2.7	63	2.2	3.1	51	2.3	3.5	41	2.4	4.0	34	2.6	4.5
200													81	2.1	2.7	66	2.2	3.1	54	2.3	3.5	44	2.4	4.0	36	2.6	4.5
220													89	2.1	2.7	73	2.2	3.1	59	2.3	3.5	48	2.4	4.0	40	2.6	4.5
240													97	2.1	2.7	79	2.2	3.1	65	2.3	3.5	52	2.4	4.0	43	2.6	4.5
260																86	2.2	3.1	70	2.3	3.5	56	2.4	4.0	47	2.6	4.5
280																92	2.2	3.1	75	2.3	3.5	61	2.4	4.0	50	2.6	4.5
300																99	2.2	3.1	81	2.3	3.5	65	2.4	4.0	54	2.6	4.5

T = Top width, Retardance "B"
D = Depth, Retardance "B"
V_2 = Velocity, Retardance "B"
V_1 = Velocity, Retardance "D"

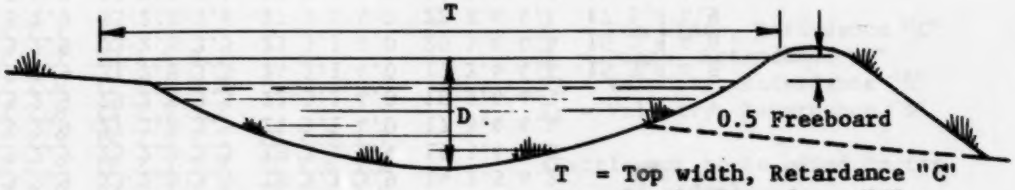
(Settlement to be added to
top of ridge.)

Exhibit 9-1 Parabolic diversion design chart (Sheet 6 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 0.25%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	11	2.9	1.6																								
30	13	2.8	1.7																								
35	15	2.8	1.7																								
40	17	2.8	1.8	11	3.2	2.1																					
45	19	2.7	1.8	13	3.1	2.2																					
50	21	2.7	1.8	14	3.1	2.2																					
55	23	2.7	1.8	15	3.1	2.3																					
60	25	2.7	1.8	17	3.0	2.3																					
65	27	2.7	1.8	18	3.0	2.3																					
70	29	2.7	1.9	19	3.0	2.3	14	3.6	2.7																		
75	31	2.7	1.9	21	3.0	2.3	15	3.5	2.8																		
80	33	2.7	1.9	22	3.0	2.4	16	3.5	2.8																		
90	37	2.7	1.9	25	3.0	2.4	17	3.5	2.8																		
100	41	2.7	1.9	28	3.0	2.4	19	3.5	2.9																		
110	45	2.7	1.9	30	3.0	2.4	21	3.4	2.9																		
120	49	2.7	1.9	33	3.0	2.4	23	3.4	2.9	16	4.1	3.3															
130	53	2.7	1.9	36	3.0	2.4	25	3.4	2.9	18	4.1	3.3															
140	57	2.7	1.9	38	3.0	2.4	27	3.4	2.9	19	4.0	3.4															
150	61	2.7	1.9	41	3.0	2.4	29	3.4	2.9	20	4.0	3.4															
160	65	2.7	1.9	44	3.0	2.4	30	3.4	3.0	21	4.0	3.4															
170	69	2.7	1.9	46	3.0	2.4	32	3.4	3.0	23	4.0	3.4	18	4.5	3.8												
180	73	2.7	1.9	49	3.0	2.4	34	3.4	3.0	24	4.0	3.5	19	4.5	3.8												
190	77	2.7	1.9	52	3.0	2.4	36	3.4	3.0	25	4.0	3.5	20	4.5	3.9												
200	81	2.7	1.9	55	3.0	2.4	38	3.4	3.0	27	3.9	3.5	21	4.4	3.9												
220	89	2.7	1.9	60	3.0	2.4	42	3.4	3.0	29	3.9	3.5	23	4.4	3.9												
240	97	2.7	1.9	65	3.0	2.5	45	3.4	3.0	32	3.9	3.6	25	4.4	4.0												
260				71	3.0	2.5	49	3.4	3.0	34	3.9	3.6	27	4.4	4.0	21	5.1	4.3									
280				76	3.0	2.5	53	3.4	3.0	37	3.9	3.6	29	4.4	4.0	22	5.1	4.3									
300				82	3.0	2.5	57	3.4	3.0	40	3.9	3.6	31	4.3	4.1	24	5.0	4.4									



T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-2 Parabolic diversion design chart (Sheet 1 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C"   Grade = 0.5%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	10	2.1	1.6																								
20	13	2.1	1.7																								
25	16	2.1	1.7	10	2.4	2.1																					
30	20	2.1	1.7	12	2.4	2.2	9	2.7	2.5																		
35	23	2.1	1.7	14	2.4	2.3	11	2.6	2.6																		
40	26	2.1	1.7	16	2.3	2.3	12	2.6	2.7																		
45	29	2.0	1.7	18	2.3	2.3	13	2.5	2.8																		
50	32	2.0	1.7	20	2.3	2.4	15	2.5	2.8	11	2.9	3.2															
55	35	2.0	1.7	22	2.3	2.4	16	2.5	2.8	12	2.9	3.3															
60	39	2.0	1.7	24	2.3	2.4	18	2.5	2.8	13	2.9	3.3															
65	42	2.0	1.8	26	2.3	2.4	19	2.5	2.9	14	2.9	3.3															
70	45	2.0	1.8	28	2.3	2.4	21	2.5	2.9	15	2.8	3.4															
75	48	2.0	1.8	30	2.3	2.4	22	2.5	2.9	16	2.8	3.4	12	3.2	3.7												
80	51	2.0	1.8	32	2.3	2.4	23	2.5	2.9	17	2.8	3.4	13	3.2	3.8												
90	57	2.0	1.8	35	2.3	2.4	26	2.5	2.9	19	2.8	3.4	15	3.2	3.8												
100	64	2.0	1.8	39	2.3	2.4	29	2.5	2.9	21	2.8	3.5	16	3.1	3.9	13	3.5	4.1									
110	70	2.0	1.8	43	2.3	2.4	32	2.5	2.9	23	2.8	3.5	18	3.1	3.9	14	3.5	4.2									
120	76	2.0	1.8	47	2.3	2.4	35	2.5	2.9	25	2.8	3.5	19	3.1	3.9	15	3.4	4.3									
130	83	2.0	1.8	51	2.3	2.4	38	2.5	2.9	27	2.8	3.5	21	3.1	4.0	17	3.4	4.4									
140	89	2.0	1.8	55	2.3	2.4	41	2.5	2.9	29	2.8	3.5	22	3.1	4.0	18	3.4	4.3									
150	95	2.0	1.8	59	2.3	2.4	44	2.5	2.9	31	2.8	3.5	24	3.1	4.0	19	3.4	4.4	15	3.8	4.8						
160				62	2.3	2.4	46	2.5	2.9	33	2.8	3.5	25	3.1	4.0	20	3.4	4.4	16	3.8	4.8						
170				66	2.3	2.4	49	2.5	2.9	35	2.8	3.6	27	3.1	4.0	22	3.4	4.4	17	3.8	4.9						
180				70	2.3	2.4	52	2.5	2.9	37	2.8	3.6	29	3.1	4.0	23	3.4	4.5	18	3.8	4.9						
190				74	2.3	2.4	55	2.5	2.9	39	2.8	3.6	30	3.1	4.0	24	3.4	4.5	19	3.8	5.0						
200				78	2.3	2.4	58	2.5	2.9	41	2.8	3.6	32	3.1	4.0	25	3.4	4.5	20	3.8	5.0	16	4.2	5.2			
220				86	2.3	2.4	64	2.5	2.9	45	2.8	3.6	35	3.1	4.0	28	3.4	4.5	22	3.7	5.0	18	4.2	5.3			
240				93	2.3	2.4	69	2.5	2.9	49	2.8	3.6	38	3.0	4.1	30	3.4	4.5	24	3.7	5.0	20	4.2	5.4			
260							75	2.5	2.9	53	2.8	3.6	41	3.0	4.1	33	3.4	4.5	26	3.7	5.0	21	4.1	5.4			
280							81	2.5	3.0	57	2.8	3.6	44	3.0	4.1	35	3.3	4.6	28	3.7	5.0	23	4.1	5.5	19	4.6	5.8
300							87	2.5	3.0	61	2.8	3.6	47	3.0	4.1	38	3.3	4.6	30	3.6	5.0	24	4.1	5.5	20	4.6	5.8

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-2 Parabolic diversion design chart (Sheet 2 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C"

Grade = 0.75%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	14	1.8	1.5																								
20	18	1.8	1.5	10	2.0	2.2																					
25	23	1.8	1.5	13	2.0	2.2																					
30	27	1.8	1.5	15	2.0	2.2	11	2.2	2.7																		
35	32	1.8	1.5	18	2.0	2.3	13	2.2	2.7	10	2.4	3.1															
40	37	1.8	1.5	20	2.0	2.3	15	2.2	2.8	11	2.4	3.2															
45	41	1.8	1.6	23	2.0	2.3	17	2.2	2.8	13	2.3	3.2															
50	45	1.8	1.6	25	2.0	2.3	18	2.1	2.9	14	2.3	3.3	10	2.7	3.7												
55	50	1.8	1.6	28	2.0	2.3	20	2.1	2.9	16	2.3	3.3	11	2.6	3.8												
60	54	1.8	1.6	30	2.0	2.3	22	2.1	2.9	17	2.3	3.3	12	2.6	3.8												
65	59	1.8	1.6	33	2.0	2.3	24	2.1	2.9	18	2.3	3.3	13	2.6	3.8	11	2.9	4.1									
70	63	1.8	1.6	35	2.0	2.3	25	2.1	2.9	20	2.3	3.3	14	2.6	3.9	12	2.9	4.2									
75	68	1.8	1.6	38	2.0	2.3	27	2.1	2.9	21	2.3	3.3	15	2.6	3.9	13	2.8	4.2									
80	72	1.8	1.6	40	2.0	2.3	29	2.1	2.9	23	2.3	3.3	16	2.6	3.9	14	2.8	4.3									
90	81	1.8	1.6	45	2.0	2.3	33	2.1	2.9	25	2.3	3.4	18	2.6	4.0	15	2.8	4.4	12	3.1	4.6						
100	90	1.8	1.6	50	2.0	2.3	36	2.1	2.9	28	2.3	3.4	20	2.6	4.0	17	2.8	4.4	13	3.1	4.8						
110	99	1.8	1.6	55	2.0	2.3	40	2.1	2.9	31	2.3	3.4	22	2.5	4.0	18	2.8	4.5	15	3.1	4.8						
120				60	2.0	2.3	43	2.1	2.9	34	2.3	3.4	24	2.5	4.0	20	2.8	4.5	16	3.0	4.8	13	3.4	5.2			
130				65	2.0	2.4	47	2.1	2.9	36	2.3	3.4	26	2.5	4.0	21	2.7	4.5	17	3.0	4.9	14	3.3	5.3			
140				70	2.0	2.4	50	2.1	2.9	39	2.3	3.4	28	2.5	4.1	23	2.7	4.5	19	3.0	4.9	15	3.3	5.3			
150				75	2.0	2.4	54	2.1	2.9	42	2.3	3.4	30	2.5	4.1	25	2.7	4.5	20	3.0	4.9	16	3.3	5.3			
160				80	2.0	2.4	58	2.1	2.9	45	2.3	3.4	32	2.5	4.1	26	2.7	4.5	21	3.0	4.9	17	3.3	5.4	14	3.6	5.8
170				85	2.0	2.4	61	2.1	2.9	47	2.3	3.4	34	2.5	4.1	28	2.7	4.5	22	3.0	5.0	18	3.3	5.4	15	3.6	5.8
180				89	2.0	2.4	65	2.1	2.9	50	2.3	3.4	36	2.5	4.1	29	2.7	4.5	24	3.0	5.0	19	3.3	5.5	16	3.6	5.9
190				94	2.0	2.4	68	2.1	2.9	53	2.3	3.4	38	2.5	4.1	31	2.7	4.6	25	3.0	5.0	21	3.3	5.5	17	3.6	5.9
200				99	2.0	2.4	72	2.1	3.0	55	2.3	3.4	40	2.5	4.1	33	2.7	4.6	26	3.0	5.0	22	3.2	5.5	18	3.6	5.9
220							79	2.1	3.0	61	2.3	3.4	44	2.5	4.1	36	2.7	4.6	29	3.0	5.0	24	3.2	5.5	19	3.6	5.9
240							86	2.1	3.0	66	2.3	3.4	48	2.5	4.1	39	2.7	4.6	32	3.0	5.0	26	3.2	5.5	21	3.6	6.0
260							93	2.1	3.0	72	2.3	3.4	52	2.5	4.1	42	2.7	4.6	34	3.0	5.0	28	3.2	5.5	23	3.6	6.0
280										77	2.3	3.4	56	2.5	4.1	45	2.7	4.6	37	3.0	5.0	30	3.2	5.5	24	3.5	6.0
300										83	2.3	3.5	60	2.5	4.1	49	2.7	4.6	39	3.0	5.0	32	3.2	5.5	26	3.5	6.0

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge)

Exhibit 9-2 Parabolic diversion design chart (Sheet 3 of 6)

V$_1$ Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V$_2$ Based on Retardance "C" Grade = 1.0%

Q	V$_1$ = 2.0			V$_1$ = 2.5			V$_1$ = 3.0			V$_1$ = 3.5			V$_1$ = 4.0			V$_1$ = 4.5			V$_1$ = 5.0			V$_1$ = 5.5			V$_1$ = 6.0		
cfs	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$	T	D	V$_2$
15	16	1.6	1.5	10	1.8	2.0																					
20	22	1.6	1.5	13	1.8	2.1																					
25	27	1.6	1.5	17	1.8	2.1	11	2.0	2.6																		
30	32	1.6	1.5	20	1.8	2.1	13	2.0	2.7	11	2.1	3.0															
35	37	1.6	1.5	23	1.8	2.2	15	2.0	2.8	12	2.1	3.1															
40	43	1.6	1.5	26	1.8	2.2	17	1.9	2.8	14	2.1	3.1	10	2.3	3.7												
45	48	1.6	1.5	29	1.8	2.2	19	1.9	2.8	16	2.1	3.2	12	2.3	3.7												
50	53	1.6	1.5	33	1.8	2.2	22	1.9	2.8	17	2.1	3.2	13	2.3	3.7	10	2.5	4.2									
55	58	1.6	1.5	36	1.8	2.2	24	1.9	2.8	19	2.0	3.3	14	2.3	3.8	11	2.5	4.3									
60	64	1.6	1.5	39	1.8	2.2	26	1.9	2.8	21	2.0	3.3	15	2.2	3.8	12	2.5	4.3									
65	69	1.6	1.5	42	1.8	2.2	28	1.9	2.8	22	2.0	3.3	17	2.2	3.8	13	2.5	4.3	10	2.7	4.7						
70	74	1.6	1.5	45	1.8	2.2	30	1.9	2.8	24	2.0	3.3	18	2.2	3.9	14	2.5	4.4	11	2.7	4.7						
75	79	1.6	1.5	49	1.8	2.2	32	1.9	2.9	26	2.0	3.3	19	2.2	3.9	15	2.5	4.5	12	2.7	4.7						
80	84	1.6	1.5	52	1.8	2.2	34	1.9	2.9	27	2.0	3.3	20	2.2	3.9	16	2.5	4.5	13	2.7	4.9						
90	95	1.6	1.5	58	1.8	2.2	38	1.9	2.9	31	2.0	3.3	23	2.2	3.9	17	2.4	4.5	14	2.7	4.9	12	2.9	5.2			
100				65	1.8	2.2	43	1.9	2.9	34	2.0	3.3	25	2.2	3.9	19	2.4	4.5	16	2.7	4.9	13	2.9	5.3			
110				71	1.8	2.2	47	1.9	2.9	37	2.0	3.3	28	2.2	3.9	21	2.4	4.5	17	2.6	5.0	14	2.9	5.3	12	3.1	5.7
120				77	1.8	2.2	51	1.9	2.9	41	2.0	3.3	30	2.2	4.0	23	2.4	4.5	19	2.6	5.0	16	2.9	5.4	13	3.1	5.7
130				84	1.8	2.2	55	1.9	2.9	44	2.0	3.3	33	2.2	4.0	25	2.4	4.5	20	2.6	5.0	17	2.9	5.4	14	3.1	5.8
140				90	1.8	2.2	59	1.9	2.9	47	2.0	3.3	35	2.2	4.0	27	2.4	4.5	22	2.6	5.0	18	2.8	5.5	15	3.1	5.8
150				96	1.8	2.2	64	1.9	2.9	51	2.0	3.3	38	2.2	4.0	29	2.4	4.5	23	2.6	5.0	19	2.8	5.5	17	3.1	5.8
160							68	1.9	2.9	54	2.0	3.3	40	2.2	4.0	30	2.4	4.5	25	2.6	5.0	20	2.8	5.5	18	3.0	6.0
170							72	1.9	2.9	57	2.0	3.3	43	2.2	4.0	32	2.4	4.5	26	2.5	5.0	22	2.8	5.5	19	3.0	6.0
180							76	1.9	2.9	61	2.0	3.4	45	2.2	4.0	34	2.4	4.5	28	2.6	5.0	23	2.8	5.5	20	3.0	6.0
190							80	1.9	2.9	64	2.0	3.4	48	2.2	4.0	36	2.4	4.5	29	2.6	5.0	24	2.8	5.5	21	3.0	6.0
200							84	1.9	2.9	67	2.0	3.4	50	2.2	4.0	38	2.4	4.5	31	2.6	5.0	25	2.8	5.5	22	3.0	6.0
220							93	1.9	2.9	74	2.0	3.4	55	2.2	4.0	42	2.4	4.5	34	2.6	5.0	28	2.8	5.5	24	3.0	6.0
240										81	2.0	3.4	60	2.2	4.0	45	2.4	4.5	37	2.6	5.0	30	2.8	5.5	26	3.0	6.0
260										87	2.0	3.4	65	2.2	4.0	49	2.4	4.5	40	2.6	5.0	33	2.8	5.5	28	3.0	6.0
280										94	2.0	3.4	70	2.2	4.0	53	2.4	4.5	43	2.6	5.0	36	2.8	5.5	30	3.0	6.0
300													75	2.2	4.0	57	2.4	4.5	46	2.5	5.0	38	2.8	5.5	32	3.0	6.0

T = Top Width, Retardance "C"
D = Depth, Retardance "C"
V$_2$ = Velocity, Retardance "C"
V$_1$ = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-2 Parabolic diversion design chart (Sheet 4 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 1.5%

Q	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	21	1.4	1.4	14	1.6	1.9																					
20	28	1.4	1.4	18	1.5	1.9	12	1.7	2.5																		
25	35	1.4	1.4	23	1.5	1.9	15	1.7	2.6	10	1.9	3.2															
30	42	1.4	1.4	27	1.5	1.9	18	1.7	2.6	12	1.8	3.2	10	2.0	3.6												
35	49	1.4	1.4	32	1.5	2.0	21	1.6	2.6	14	1.8	3.3	11	1.9	3.7	10	2.1	4.1									
40	56	1.4	1.4	36	1.5	2.0	24	1.6	2.6	16	1.8	3.3	13	1.9	3.7	11	2.1	4.2									
45	63	1.4	1.4	41	1.5	2.0	27	1.6	2.6	18	1.8	3.4	15	1.9	3.8	12	2.0	4.3									
50	70	1.4	1.4	45	1.5	2.0	30	1.6	2.7	20	1.8	3.4	16	1.9	3.9	13	2.0	4.3	10	2.3	4.8						
55	76	1.4	1.5	50	1.5	2.0	33	1.6	2.7	22	1.8	3.4	18	1.9	3.9	14	2.0	4.3	11	2.3	4.9						
60	83	1.4	1.5	54	1.5	2.0	35	1.6	2.7	24	1.8	3.4	19	1.9	3.9	16	2.0	4.4	12	2.3	4.9	10	2.4	5.2			
65	90	1.4	1.5	58	1.5	2.0	38	1.6	2.7	26	1.8	3.4	21	1.9	3.9	17	2.0	4.4	13	2.2	5.0	11	2.4	5.3			
70	97	1.4	1.5	63	1.5	2.0	41	1.6	2.7	28	1.8	3.4	22	1.9	3.9	18	2.0	4.4	14	2.2	5.0	12	2.4	5.4	10	2.6	5.6
75				67	1.5	2.0	44	1.6	2.7	30	1.8	3.4	24	1.9	3.9	19	2.0	4.4	15	2.2	5.0	12	2.4	5.4	11	2.6	5.6
80				72	1.5	2.0	47	1.6	2.7	32	1.8	3.4	26	1.9	3.9	21	2.0	4.4	16	2.2	5.0	13	2.4	5.4	12	2.5	5.8
90				80	1.5	2.0	53	1.6	2.7	36	1.8	3.5	29	1.9	3.9	23	2.0	4.4	18	2.2	5.0	15	2.4	5.4	13	2.5	5.9
100				89	1.5	2.0	59	1.6	2.7	39	1.8	3.5	32	1.9	3.9	26	2.0	4.5	20	2.2	5.0	17	2.4	5.4	14	2.5	6.0
110				98	1.5	2.0	64	1.6	2.7	43	1.8	3.5	35	1.9	3.9	28	2.0	4.5	22	2.2	5.0	18	2.3	5.5	15	2.5	6.0
120							70	1.6	2.7	47	1.8	3.5	38	1.9	4.0	31	2.0	4.5	24	2.2	5.0	20	2.3	5.5	17	2.5	6.0
130							76	1.6	2.7	51	1.8	3.5	41	1.9	4.0	33	2.0	4.5	26	2.2	5.0	21	2.3	5.5	18	2.5	6.0
140							82	1.6	2.7	55	1.8	3.5	44	1.9	4.0	36	2.0	4.5	27	2.2	5.0	23	2.3	5.5	19	2.5	6.0
150							87	1.6	2.7	59	1.8	3.5	47	1.9	4.0	39	2.0	4.5	29	2.2	5.0	25	2.3	5.5	21	2.5	6.0
160							93	1.6	2.7	63	1.8	3.5	51	1.9	4.0	41	2.0	4.5	31	2.2	5.0	26	2.3	5.5	22	2.5	6.0
170							99	1.6	2.7	67	1.8	3.5	54	1.9	4.0	44	2.0	4.5	33	2.2	5.0	28	2.3	5.5	23	2.5	6.0
180										70	1.8	3.5	57	1.9	4.0	46	2.0	4.5	35	2.2	5.0	29	2.3	5.5	25	2.5	6.0
190										74	1.8	3.5	60	1.9	4.0	49	2.0	4.5	37	2.2	5.0	31	2.3	5.5	26	2.5	6.0
200										78	1.8	3.5	63	1.9	4.0	51	2.0	4.5	39	2.2	5.0	33	2.3	5.5	27	2.5	6.0
220										86	1.8	3.5	69	1.9	4.0	56	2.0	4.5	43	2.2	5.0	36	2.3	5.5	30	2.5	6.0
240										93	1.8	3.5	75	1.9	4.0	61	2.0	4.5	47	2.2	5.0	39	2.3	5.5	33	2.5	6.0
260													82	1.9	4.0	66	2.0	4.5	51	2.2	5.0	42	2.3	5.5	35	2.5	6.0
280													88	1.9	4.0	71	2.0	4.5	54	2.2	5.0	46	2.3	5.5	38	2.5	6.0
300													94	1.9	4.0	76	2.0	4.5	58	2.2	5.0	49	2.3	5.5	41	2.5	6.0

T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"
(Settlement to be added to top of ridge.)

Exhibit 9-2 Parabolic diversion design chart (Sheet 5 of 6)

V_1 Based on Permissible Velocity of the Soil With Retardance "D"

Top Width, Depth & V_2 Based on Retardance "C" Grade = 2.0%

Q	$V_1 = 2.0$			$V_1 = 2.5$			$V_1 = 3.0$			$V_1 = 3.5$			$V_1 = 4.0$			$V_1 = 4.5$			$V_1 = 5.0$			$V_1 = 5.5$			$V_1 = 6.0$		
cfs	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	27	1.3	1.3	16	1.4	1.9	11	1.5	2.4																		
20	35	1.3	1.3	21	1.4	1.9	15	1.5	2.4	11	1.6	3.0															
25	44	1.3	1.3	27	1.4	1.9	19	1.5	2.4	13	1.6	3.0	10	1.8	3.7												
30	53	1.3	1.3	32	1.4	1.9	23	1.5	2.5	16	1.6	3.0	11	1.7	3.7	10	1.8	4.2									
35	61	1.3	1.3	37	1.4	1.9	26	1.5	2.5	19	1.6	3.1	13	1.7	3.8	11	1.8	4.2									
40	70	1.3	1.3	42	1.4	1.9	30	1.5	2.5	21	1.6	3.1	15	1.7	3.8	12	1.8	4.3	10	2.0	4.7						
45	78	1.3	1.4	48	1.4	1.9	34	1.5	2.5	24	1.6	3.1	17	1.7	3.8	14	1.8	4.3	11	1.9	4.8						
50	87	1.3	1.4	53	1.4	1.9	38	1.5	2.5	26	1.6	3.1	19	1.7	3.8	15	1.8	4.3	13	1.9	4.8	10	2.1	5.3			
55	95	1.3	1.4	58	1.4	1.9	41	1.5	2.5	29	1.6	3.1	21	1.7	3.8	17	1.8	4.3	14	1.9	4.9	11	2.1	5.3			
60				63	1.4	1.9	45	1.5	2.5	32	1.6	3.1	23	1.7	3.9	18	1.8	4.4	15	1.9	4.9	12	2.1	5.3	10	2.2	5.7
65				68	1.4	1.9	49	1.5	2.5	34	1.6	3.1	24	1.7	3.9	20	1.8	4.4	16	1.9	4.9	13	2.1	5.4	11	2.2	5.7
70				73	1.4	1.9	52	1.5	2.5	37	1.6	3.1	26	1.7	3.9	22	1.8	4.4	18	1.9	4.9	14	2.1	5.4	12	2.2	5.8
75				78	1.4	1.9	56	1.5	2.5	39	1.6	3.1	28	1.7	3.9	23	1.8	4.4	19	1.9	4.9	15	2.1	5.4	13	2.2	5.9
80				83	1.4	2.0	60	1.5	2.5	42	1.6	3.1	30	1.7	3.9	24	1.8	4.4	20	1.9	4.9	16	2.1	5.4	14	2.2	5.9
90				94	1.4	2.0	67	1.5	2.5	47	1.6	3.2	34	1.7	3.9	28	1.8	4.4	22	1.9	4.9	18	2.1	5.5	15	2.2	5.9
100							74	1.5	2.5	52	1.6	3.2	37	1.7	3.9	31	1.8	4.4	25	1.9	5.0	20	2.1	5.5	17	2.2	6.0
110							81	1.5	2.5	57	1.6	3.2	41	1.7	3.9	34	1.8	4.4	27	1.9	5.0	22	2.0	5.5	19	2.2	6.0
120							89	1.5	2.5	62	1.6	3.2	45	1.7	3.9	37	1.8	4.4	30	1.9	5.0	24	2.0	5.5	20	2.2	6.0
130							96	1.5	2.5	67	1.6	3.2	48	1.7	3.9	40	1.8	4.5	32	1.9	5.0	26	2.0	5.5	22	2.2	6.0
140										73	1.6	3.2	52	1.7	4.0	42	1.8	4.5	35	1.9	5.0	28	2.0	5.5	23	2.2	6.0
150										78	1.6	3.2	56	1.7	4.0	46	1.8	4.5	37	1.9	5.0	30	2.0	5.5	25	2.2	6.0
160										83	1.6	3.2	59	1.7	4.0	48	1.8	4.5	39	1.9	5.0	32	2.0	5.5	27	2.2	6.0
170										88	1.6	3.2	63	1.7	4.0	51	1.8	4.5	42	1.9	5.0	34	2.0	5.5	28	2.2	6.0
180										93	1.6	3.2	67	1.7	4.0	54	1.8	4.5	44	1.9	5.0	36	2.0	5.5	30	2.2	6.0
190										98	1.6	3.2	70	1.7	4.0	57	1.8	4.5	47	1.9	5.0	38	2.0	5.5	32	2.2	6.0
200													74	1.7	4.0	60	1.8	4.5	49	1.9	5.0	40	2.0	5.5	33	2.2	6.0
220													81	1.7	4.0	66	1.8	4.5	54	1.9	5.0	44	2.0	5.5	37	2.2	6.0
240													88	1.7	4.0	72	1.8	4.5	59	1.9	5.0	48	2.0	5.5	40	2.2	6.0
260													96	1.7	4.0	78	1.8	4.5	64	1.9	5.0	51	2.0	5.5	43	2.2	6.0
280																84	1.8	4.5	69	1.9	5.0	55	2.0	5.5	46	2.2	6.0
300																90	1.8	4.5	73	1.9	5.0	59	2.0	5.5	50	2.2	6.0

T = Top width, Retardance "C"
D = Depth, Retardance "C"
V_2 = Velocity, Retardance "C"
V_1 = Velocity, Retardance "D"

(Settlement to be added to top of ridge.)

Exhibit 9-2 Parabolic diversion design chart (Sheet 6 of 6)

(Based on Handbook of Channel Design, SCS-TP-61)

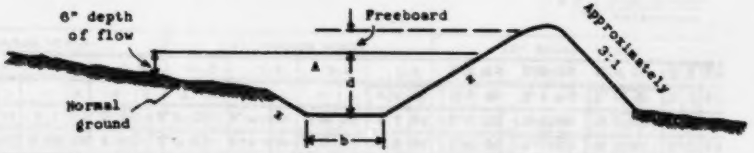
● 3:1 Side Slopes
"D" Retardance

	Triangular								6' bottom width								8' bottom width								10' bottom width								12' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.9	11	1.8	10	1.7	9	1.6	8	1.3	12	1.1	10	1.0	9	0.9	8	1.2	13	1.1	11	1.0	10	0.9	9	1.1	14	1.0	12	0.9	11	0.8	10	1.0	14	0.9	12	0.8	11	0.7	10
20	2.2	15	2.1	13	1.9	11	1.8	10	1.5	16	1.4	14	1.2	12	1.1	10	1.4	17	1.3	16	1.2	14	1.1	12	1.3	18	1.2	16	1.0	13	0.9	11	1.2	19	1.1	17	1.0	15	0.9	13
30	2.5	19	2.3	16	2.2	15	2.0	12	1.8	21	1.6	17	1.5	16	1.3	13	1.7	22	1.5	19	1.4	17	1.2	14	1.5	22	1.4	20	1.2	16	1.1	15	1.3	21	1.2	19	1.2	19	1.1	17
40	2.6	20	2.5	19	2.3	16	2.2	15	2.0	24	1.8	21	1.7	19	1.5	16	1.8	24	1.7	22	1.5	19	1.4	17	1.7	26	1.5	22	1.4	20	1.2	16	1.6	27	1.5	25	1.3	21	1.2	19
60	3.0	27	2.9	24	2.7	22	2.5	19	2.3	30	2.1	26	1.9	22	1.7	19	2.1	30	1.9	26	1.8	24	1.6	21	2.0	32	1.8	28	1.7	26	1.5	22	1.8	31	1.6	27	1.5	25	1.3	21
80			3.1	29	2.9	25	2.7	22	2.5	34	2.3	30	2.1	26	1.9	22	2.4	37	2.2	32	2.0	28	1.8	24	2.3	39	2.1	34	1.9	30	1.7	26	2.1	38	1.9	34	1.8	31	1.6	27
100					3.1	29	2.9	25	2.8	40	2.5	34	2.3	30	2.1	26	2.6	41	2.4	37	2.2	32	2.0	28	2.4	41	2.2	37	2.1	34	1.9	30	2.3	44	2.1	38	1.9	34	1.7	29
120							3.0	27	3.0	45	2.8	40	2.5	34	2.3	30	2.8	46	2.5	39	2.3	34	2.1	30	2.6	46	2.4	41	2.2	37	2.0	32	2.5	50	2.3	44	2.1	38	1.9	34
140											2.9	43	2.6	36	2.4	32	2.9	48	2.7	44	2.5	39	2.3	34	2.7	49	2.5	44	2.3	39	2.1	34	2.6	52	2.4	46	2.2	41	2.0	36
160											3.0	45	2.8	40	2.6	36	3.1	51	2.9	48	2.7	44	2.5	39	2.9	54	2.7	49	2.5	44	2.3	39	2.7	54	2.5	50	2.3	44	2.1	38
180																							2.6	41	3.0	57	2.8	51	2.6	46	2.4	41	2.8	57	2.6	52	2.4	46	2.2	41
200																															2.5	44	2.9	60	2.7	54	2.5	50	2.3	44
220																																	3.0	63	2.8	57	2.7	54	2.5	50

NOTE: For diversions built on slopes under 2% the available cross-sectional area above normal ground will allow a reduction in design depth as follows:

For land slopes of 1% or less reduce depth of flow (taken from Design Table) 20%.
For land slopes of 1% to 2% reduce depth of flow (taken from Design Table) 10%.
For land slopes greater than 2% use depth of flow taken from Design Table.

For Example: A diversion 6 feet wide with a 2.5 foot depth of flow is required to remove 120 c.f.s. on a 0.4% grade. If this is built on a 1% slope the depth may be reduced 20% thus obtaining a flow depth of 2.0 feet. The required cross-sectional area of the channel plus that above normal ground line will be 34 square feet corresponding to the 2.5 foot depth. The overall height of diversion will be 2.0 feet plus 0.5 foot freeboard or 2.5 feet, instead of the original 3.0 feet.



d = depth of flow, feet
b = bottom width of channel, feet
A = channel capacity, sq. ft., including area below 0.5' freeboard and excluding any area less than 0.5' depth of flow
z = side slope of channel (horizontal to vertical)

IMPORTANT: To all designed depths of flow add freeboard required by State Standards and Specifications to obtain overall height of terrace above bottom of channel. For final check on cross-sectional area subtract required freeboard from settled height of diversion and provide for cross-sectional area shown in table.

Exhibit 9-3 Diversion design table - "D" Retardance (V and Trapezoidal Section)
(Sheet 1 of 2)

3/27/53 4-L-8618-1

(Based on Handbook of Channel Design, SCS-TP-61)

● 4:1 Side Slopes
"D" Retardance

	Triangular								6' bottom width								8' bottom width								10' bottom width								12' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.8	13	1.7	12	1.6	11	1.5	10	1.2	13	1.1	11	1.0	10	0.9	9	1.1	14	1.0	13	0.9	11	0.8	10	1.1	14	1.0	13	0.9	12	0.8	11	1.0	15	0.9	14	0.8	13	0.7	12
20	2.1	18	2.0	16	1.8	13	1.7	12	1.5	18	1.4	16	1.2	13	1.1	11	1.4	19	1.3	17	1.2	15	1.1	14	1.3	20	1.2	18	1.0	14	0.9	12	1.2	20	1.1	18	1.0	16	0.9	14
30	2.4	23	2.2	19	2.1	18	1.9	14	1.8	24	1.6	20	1.5	19	1.3	15	1.7	25	1.5	21	1.4	19	1.2	15	1.5	24	1.4	22	1.2	18	1.1	16	1.3	22	1.2	20	1.2	20	1.1	18
40	2.5	25	2.4	23	2.2	19	2.1	18	1.9	26	1.8	24	1.6	20	1.5	18	1.8	27	1.7	25	1.5	21	1.4	19	1.6	26	1.5	24	1.3	20	1.2	18	1.6	29	1.5	27	1.3	22	1.2	20
60	2.8	31	2.6	27	2.5	25	2.3	21	2.2	33	2.0	28	1.9	26	1.7	22	2.0	32	1.9	30	1.7	25	1.6	23	1.9	33	1.8	31	1.6	26	1.5	24	1.7	32	1.6	29	1.4	25	1.3	22
80	3.1	38	2.9	34	2.7	29	2.5	25	2.4	37	2.2	33	2.1	30	1.9	26	2.3	40	2.1	34	2.0	32	1.8	27	2.2	41	2.0	36	1.8	31	1.6	26	2.0	40	1.9	37	1.7	32	1.6	29
100			3.1	38	2.9	34	2.7	29	2.7	45	2.5	40	2.3	35	2.1	30	2.5	45	2.3	40	2.1	34	1.9	30	2.3	44	2.1	39	2.0	36	1.8	31	2.2	46	2.0	40	1.9	37	1.7	32
120							2.9	31	2.9	51	2.7	45	2.4	37	2.2	33	2.7	51	2.5	45	2.3	40	2.1	34	2.5	50	2.3	44	2.2	41	2.0	36	2.4	52	2.2	46	2.0	40	1.8	35
140									3.0	54	2.9	48	2.6	43	2.4	37	2.8	54	2.6	48	2.5	45	2.3	40	2.6	53	2.4	47	2.3	44	2.1	39	2.5	55	2.3	49	2.2	46	2.0	40
160									3.1	57	2.9	51	2.8	48	2.6	43	3.0	60	2.8	54	2.6	48	2.4	42	2.8	59	2.6	53	2.5	50	2.3	44	2.7	62	2.5	55	2.3	49	2.1	43
180																							2.5	45	2.9	63	2.7	56	2.6	53	2.4	47	2.8	65	2.6	58	2.4	52	2.2	46
200																															2.5	50	2.9	68	2.7	62	2.5	55	2.3	49
220																																	3.0	72	2.8	65	2.6	58	2.4	52

● 6:1 Side Slopes
"D" Retardance

	Triangular								6' bottom width								8' bottom width								10' bottom width								12' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q-cfs	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
10	1.6	15	1.5	14	1.4	13	1.3	11	1.2	16	1.1	14	1.0	12	0.9	10	1.1	16	1.0	14	0.9	13	0.9	11	1.1	17	1.0	15	0.9	13	0.8	12	1.0	17	0.9	15	0.9	14	0.7	12
20	1.9	22	1.8	19	1.6	15	1.5	14	1.5	23	1.4	20	1.2	16	1.1	14	1.4	23	1.3	21	1.1	16	1.0	14	1.3	21	1.2	20	1.1	19	1.0	16	1.3	25	1.2	23	1.0	17	0.9	16
30	2.1	27	2.0	24	1.8	19	1.7	17	1.7	28	1.5	23	1.4	20	1.2	16	1.6	28	1.5	26	1.3	21	1.2	18	1.4	26	1.3	23	1.2	20	1.1	18	1.4	29	1.3	27	1.1	20	1.0	18
40	2.3	32	2.2	29	2.0	24	1.8	19	1.8	30	1.7	28	1.5	23	1.4	20	1.7	31	1.6	28	1.4	23	1.3	21	1.5	29	1.4	26	1.3	23	1.2	20	1.5	32	1.4	29	1.3	27	1.2	22
60	2.5	36	2.3	32	2.2	29	2.0	24	2.0	36	1.9	33	1.7	28	1.6	25	1.9	37	1.8	34	1.6	28	1.5	26	1.8	38	1.7	34	1.5	29	1.4	26	1.6	34	1.5	32	1.4	29	1.3	27
80	2.7	44	2.5	36	2.4	35	2.2	29	2.2	42	2.1	39	1.9	33	1.8	30	2.1	43	2.0	40	1.8	34	1.7	31	2.0	44	1.9	41	1.7	34	1.6	31	1.8	41	1.7	37	1.6	34	1.5	32
100	2.9	51	2.7	44	2.6	41	2.4	35	2.4	49	2.2	42	2.1	39	1.9	33	2.3	50	2.1	43	2.0	40	1.8	34	2.2	51	2.0	44	1.9	41	1.7	34	2.1	51	1.9	45	1.8	41	1.6	34
120	3.0	54	2.8	47	2.7	44	2.5	38	2.6	56	2.4	49	2.3	46	2.1	39	2.5	56	2.3	50	2.2	47	2.0	40	2.3	55	2.2	51	2.0	44	1.9	41	2.2	55	2.0	48	1.9	45	1.7	37
140									2.7	61	2.6	56	2.4	49	2.3	46	2.6	61	2.5	56	2.3	50	2.2	47	2.5	63	2.3	55	2.2	51	2.0	44	2.4	64	2.2	55	2.1	51	1.9	45
160									2.9	68	2.8	64	2.6	56	2.5	53	2.8	67	2.6	61	2.5	56	2.3	50	2.7	71	2.5	63	2.4	59	2.2	51	2.6	70	2.4	64	2.3	59	2.1	51
180																	2.9	71	2.7	64	2.6	61	2.4	54	2.8	75	2.6	67	2.5	63	2.3	55	2.7	76	2.5	68	2.4	63	2.2	55
200																	3.0	72	2.8	67	2.6	61	2.4	54	2.9	79	2.7	77	2.6	67	2.4	59	2.8	81	2.6	72	2.5	68	2.3	59
220																							2.5	58							2.4	59	2.9	85	2.7	76	2.5	68	2.3	59
240																															2.5	63							2.4	64
260																																							2.5	68

4-L-8618-2

Exhibit 9-3 Diversion design table - "D" Retardance (V and Trapezoidal Section) (Sheet 2 of 2)

(Based on Handbook of Channel Design, SCS-TP-61)

● 3:1 Side Slopes
"C" Retardance

Grade	Triangular								6' bottom								8' bottom								10' bottom								12' bottom							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
0	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	2.5	19	2.3	16	2.1	13	1.9	11	1.9	22	1.7	19	1.5	16	1.4	14	1.7	22	1.5	19	1.4	17	1.3	15	1.6	24	1.4	20	1.3	18	1.2	16								
30			2.5	19	2.3	16	2.2	15	2.0	24	1.8	21	1.7	19	1.5	16	1.9	26	1.7	22	1.5	19	1.4	17	1.7	26	1.5	22	1.4	20	1.3	18	1.6	27	1.4	23	1.3	21	1.2	19
40					2.5	19	2.4	17	2.2	28	2.0	24	1.9	22	1.7	19	2.0	28	1.8	24	1.6	21	1.5	19	1.9	30	1.7	26	1.5	22	1.4	20	1.8	31	1.6	27	1.5	25	1.4	23
50							2.5	19	2.3	30	2.1	26	2.0	24	1.8	21	2.2	32	2.0	28	1.8	24	1.6	21	2.0	32	1.8	28	1.6	24	1.5	22	1.9	34	1.7	29	1.6	27	1.5	25
60									2.5	34	2.3	30	2.1	26	1.9	22	2.3	34	2.1	30	1.9	26	1.8	24	2.2	37	2.0	32	1.8	26	1.6	24	2.0	36	1.8	31	1.7	29	1.6	27
80											2.5	34	2.3	30	2.1	26	2.5	39	2.3	34	2.1	30	1.9	26	2.4	41	2.2	37	2.0	32	1.8	28	2.2	41	2.0	36	1.9	34	1.7	29
100													2.5	34	2.3	30			2.5	39	2.3	34	2.1	30			2.4	41	2.2	37	2.0	32	2.5	49	2.2	41	2.0	36	1.8	31
120															2.5	34					2.5	39	2.3	34					2.3	39	2.1	34			2.4	46	2.2	41	2.0	36
140																							2.4	39					2.5	44	2.3	39					2.3	43	2.1	38
160																															2.4	41					2.4	46	2.2	41
180																															2.5	44							2.4	46
200																																							2.5	49
220																																							2.6	51

● 4:1 Side Slopes
"C" Retardance

Grade	Triangular								6' bottom width								8' bottom width								10' bottom width								12' bottom width							
	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
0	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
30	2.5	25	2.4	23	2.3	21	2.1	18	2.0	28	1.8	24	1.6	20	1.5	18	1.8	27	1.7	25	1.5	21	1.4	19	1.8	31	1.6	26	1.4	22	1.3	20	1.7	32	1.6	29	1.4	25	1.2	20
40			2.5	25	2.4	23	2.2	19	2.1	30	1.9	26	1.7	22	1.6	20	2.0	32	1.8	27	1.6	23	1.5	21	1.9	33	1.7	29	1.5	24	1.4	22	1.8	35	1.7	32	1.5	27	1.3	22
50					2.5	25	2.4	23	2.3	35	2.1	30	1.9	26	1.7	22	2.1	34	1.9	30	1.7	25	1.6	23	2.0	36	1.8	31	1.6	26	1.5	24	1.9	37	1.8	35	1.6	29	1.4	25
60							2.5	25	2.4	37	2.2	33	2.0	28	1.9	26	2.3	40	2.1	34	1.9	30	1.7	25	2.1	39	1.9	34	1.7	29	1.6	26	2.0	40	1.9	37	1.7	32	1.5	27
80											2.4	37	2.2	33	2.0	28	2.5	45	2.3	40	2.1	34	1.9	30	2.3	44	2.1	39	1.9	34	1.8	31	2.2	46	2.0	40	1.8	35	1.7	32
100											2.5	40	2.3	35	2.2	33			2.5	45	2.3	40	2.0	32	2.5	50	2.3	44	2.1	39	1.9	34	2.3	49	2.1	43	2.0	40	1.8	35
120													2.5	40	2.4	37					2.4	42	2.2	37			2.5	50	2.3	44	2.1	39	2.5	55	2.3	49	2.2	46	2.0	40
140															2.5	40					2.5	45	2.3	40					2.4	47	2.2	41			2.5	55	2.3	49	2.1	43
160																							2.5	45					2.5	50	2.3	44					2.4	52	2.2	46
180																															2.4	47					2.5	55	2.3	49
200																															2.5	50							2.4	52
220																																							2.5	55

Exhibit 9-4 Diversion design table - "C" Retardance (V and Trapezoidal Section)
(Sheet 1 of 2)

10-26-55 4-L-10122-1

● 6:1 Side Slopes
"C" Retardance

(Based on Handbook of Channel Design, SCS-TP-61)

	Triangular								6' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	2.2	29	2.1	26	1.9	22	1.8	19	1.8	30	1.7	28	1.6	25	1.4	20
30	2.4	35	2.2	29	2.1	26	1.9	22	2.0	36	1.9	33	1.7	28	1.5	23
40	2.5	38	2.3	32	2.2	29	2.0	24	2.1	39	2.0	36	1.8	30	1.6	25
50			2.5	38	2.3	32	2.1	26	2.2	42	2.1	39	1.9	33	1.7	28
60					2.4	35	2.2	29	2.3	46	2.2	42	2.0	36	1.8	30
80					2.5	38	2.3	32	2.5	53	2.3	46	2.1	39	1.9	33
100							2.5	38			2.5	53	2.3	46	2.1	39
120													2.4	49	2.2	42
140													2.5	53	2.3	46
160															2.4	49
180															2.5	53
200																
220																

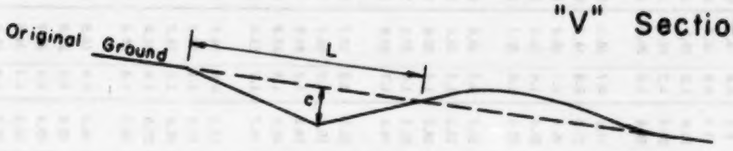
	8' bottom width								10' bottom width							
Grade	0.2		0.3		0.4		0.5		0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A	d	A	d	A	d	A	d	A
20	1.7	31	1.6	28	1.5	26	1.3	21	1.6	31	1.5	29	1.4	26	1.2	20
30	1.8	34	1.7	31	1.6	28	1.4	23	1.8	38	1.7	34	1.5	29	1.3	23
40	2.0	40	1.9	37	1.7	31	1.5	26	1.9	41	1.8	38	1.6	31	1.4	26
50	2.1	43	2.0	40	1.8	34	1.6	28	2.0	44	1.9	41	1.7	34	1.5	29
60	2.2	47	2.1	43	1.9	37	1.7	31	2.1	47	2.0	44	1.8	38	1.6	31
80	2.4	54	2.2	47	2.0	40	1.8	34	2.3	55	2.1	47	1.9	41	1.7	34
100	2.5	58	2.4	54	2.2	47	2.0	40	2.4	59	2.3	55	2.1	47	1.9	41
120			2.5	58	2.3	50	2.1	43	2.5	63	2.4	59	2.2	51	2.0	44
140					2.4	54	2.2	47			2.5	63	2.3	55	2.1	47
160					2.5	58	2.3	50					2.4	59	2.2	51
180							2.4	54					2.5	63	2.3	55
200							2.5	58							2.4	59
220															2.5	63

	12' bottom width							
Grade	0.2		0.3		0.4		0.5	
Q	d	A	d	A	d	A	d	A
20	1.5	32	1.4	29	1.3	27	1.2	22
30	1.7	37	1.6	34	1.4	29	1.3	27
40	1.8	41	1.7	37	1.5	32	1.3	27
50	1.9	45	1.8	41	1.6	34	1.4	29
60	2.0	48	1.9	45	1.8	41	1.6	34
80	2.2	55	2.1	52	1.9	45	1.7	37
100	2.3	59	2.2	55	2.0	48	1.8	41
120	2.4	64	2.3	59	2.1	52	1.9	45
140	2.5	68	2.4	64	2.2	55	2.0	48
160			2.5	68	2.3	59	2.1	52
180					2.4	64	2.2	55
200					2.5	68	2.2	55
220							2.3	59

4-L-10122-2

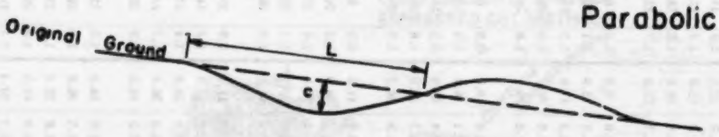
Exhibit 9-4 Diversion design table - "C" Retardance (V and Trapezoidal Section)(Sheet 2 of 2)

"V" Section



Depth of Cut "C" Ft.	Width of Excavation "L" in Feet										
	10	11	12	13	14	15	16	17	18	19	20
0.5	9.3	10.2	11.1	12.0	13.0	13.9	14.8	15.7	16.7	17.6	18.5
0.6	11.1	12.2	13.3	14.4	15.6	16.7	17.8	18.9	20.0	21.1	22.2
0.7	13.0	14.3	15.6	16.9	18.1	19.4	20.7	22.0	23.3	24.6	25.9
0.8	14.8	16.3	17.8	19.3	20.7	22.2	23.7	25.2	26.7	28.1	29.6
0.9	16.7	18.3	20.0	21.7	23.3	25.0	26.7	28.3	30.0	31.7	33.3
1.0	18.5	20.4	22.2	24.1	25.9	27.8	29.6	31.5	33.3	35.2	37.0
1.1	20.4	22.4	24.4	26.5	28.5	30.6	32.6	34.6	36.7	38.7	40.7
1.2	22.2	24.4	26.7	28.9	31.1	33.3	35.6	37.8	40.0	42.2	44.4
1.3	24.1	26.5	28.9	31.3	33.7	36.1	38.5	40.9	43.3	45.7	48.1
1.4	25.9	28.5	31.1	33.7	36.3	38.9	41.5	44.1	46.7	49.3	51.9
1.5	27.8	30.6	33.3	36.1	38.9	41.7	44.4	47.2	50.0	52.8	55.6

Parabolic Section



Depth of Cut "C" Ft.	Width of Excavation "L" in Feet										
	10	11	12	13	14	15	16	17	18	19	20
0.5	12.3	13.6	14.8	16.0	17.3	18.5	19.8	21.0	22.2	23.4	24.7
0.6	14.8	16.3	17.8	19.2	20.7	22.2	23.7	25.2	26.7	28.1	29.6
0.7	17.3	19.0	20.7	22.5	24.2	25.9	27.7	29.4	31.1	32.8	34.6
0.8	19.8	21.7	23.7	25.7	27.6	29.6	31.6	33.6	35.6	37.5	39.5
0.9	22.2	24.4	26.7	28.9	31.1	33.3	35.6	37.8	40.0	42.2	44.4
1.0	24.7	27.2	29.6	32.1	34.6	37.0	39.5	42.0	44.4	46.9	49.4
1.1	27.2	29.9	32.6	35.3	38.0	40.7	43.4	46.2	48.9	51.6	54.3
1.2	29.6	32.6	35.6	38.5	41.5	44.4	47.4	50.4	53.3	56.3	59.2
1.3	32.1	35.3	38.5	41.7	44.9	48.1	51.4	54.6	57.8	61.0	64.2
1.4	34.6	38.0	41.5	44.9	48.4	51.8	55.3	58.8	62.2	65.7	69.1
1.5	37.0	40.7	44.4	48.1	51.8	55.6	59.3	63.0	66.7	70.4	74.1

Exhibit 9-5 Cubic yards of excavation per 100 linear feet of diversion

(This table is applicable only to diversions designed by using Exhibits 9-3 and 9-4)

Depth of Flow Plus 0.5 Foot Freeboard	V Bottom						6 Foot Bottom						8 Foot Bottom						10 Foot Bottom						12 Foot Bottom					
	3:1		4:1		6:1		3:1		4:1		6:1		3:1		4:1		6:1		3:1		4:1		6:1		3;1		4:1		6:1	
	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.	d	Exc. A. Sq. Ft.
1% Slope																														
1.5	1.0	3.0	0.9	3.3	0.8	3.9	0.7	5.7	0.7	6.2	0.7	7.2	0.7	7.1	0.7	7.6	0.7	8.6	0.6	7.1	0.6	7.5	0.6	8.2	0.6	8.3	0.6	8.7	0.6	9.4
2.0	1.3	5.1	1.2	5.8	1.1	7.3	1.0	9.0	1.0	10.0	1.0	12.0	1.0	11.0	1.0	12.0	1.0	14.0	0.8	9.9	0.8	10.6	0.8	11.9	0.8	11.5	0.8	12.2	0.8	13.5
2.5	1.6	7.7	1.5	9.0	1.4	11.8	1.2	11.5	1.2	13.0	1.2	15.9	1.2	13.9	1.2	15.4	1.2	18.3	1.0	13.0	1.0	14.0	1.0	16.1	1.0	15.0	1.0	16.0	1.0	18.1
3.0	1.9	10.9	1.8	13.0	1.7	17.4	1.5	15.8	1.5	18.0	1.5	22.6	1.5	18.8	1.5	21.0	1.5	25.6	1.3	18.1	1.3	19.8	1.3	23.2	1.3	20.7	1.3	22.4	1.3	25.8
3.5	2.1	13.3	2.0	16.0	1.9	21.7	1.7	18.9	1.7	21.8	1.7	27.9	1.7	22.3	1.7	25.2	1.7	31.0	1.5	21.8	1.6	26.3	1.6	31.5	1.5	24.8	1.6	29.5	1.6	34.7
2% Slope																														
1.5	1.0	3.0	1.0	4.0	0.9	4.7	0.8	6.8	0.8	7.4	0.8	8.6	0.8	8.4	0.8	9.1	0.8	10.3	0.7	8.5	0.7	9.1	0.7	10.0	0.7	10.0	0.7	10.5	0.7	11.4
2.0	1.3	5.1	1.3	6.8	1.2	8.4	1.1	10.3	1.1	11.5	1.1	13.8	1.1	12.5	1.1	13.8	1.1	16.0	0.9	11.5	0.9	12.4	0.9	13.9	0.9	13.3	0.9	14.2	0.9	15.8
2.5	1.6	7.7	1.6	10.3	1.5	13.2	1.3	12.9	1.3	14.7	1.3	17.8	1.3	15.6	1.3	17.3	1.3	20.5	1.1	14.7	1.1	16.0	1.1	18.3	1.1	16.9	1.1	18.2	1.1	20.5
3.0	1.9	10.9	1.9	14.5	1.8	20.0	1.6	17.4	1.6	20.0	1.6	24.7	1.6	20.6	1.6	23.2	1.6	28.0	1.4	20.0	1.4	22.0	1.4	25.7	1.4	22.8	1.4	24.9	1.4	28.5
3.5	2.2	14.6	2.1	17.8	2.0	23.4	1.8	20.6	1.8	23.9	1.8	29.9	1.8	24.2	1.8	27.6	1.8	33.6	1.6	23.8	1.6	26.5	1.7	34.2	1.6	27.0	1.6	29.7	1.7	37.6
3% Slope																														
1.5	1.1	3.7	1.1	4.9	1.0	6.2	0.8	6.8	0.8	7.5	0.8	9.0	0.8	8.4	0.8	9.2	0.8	10.7	0.7	8.6	0.7	9.2	0.7	10.4	0.7	10.7	0.7	10.8	0.7	11.9
2.0	1.3	5.1	1.3	6.9	1.3	9.8	1.1	10.3	1.1	11.6	1.1	14.4	1.1	12.6	1.1	13.9	1.1	16.7	1.0	13.2	1.0	14.3	1.0	16.7	1.0	15.2	1.0	16.4	1.0	18.8
2.5	1.7	8.8	1.6	10.4	1.5	13.9	1.3	13.0	1.3	14.8	1.4	20.9	1.3	15.7	1.3	17.5	1.4	23.8	1.2	16.5	1.2	18.1	1.2	21.5	1.2	19.0	1.2	20.6	1.2	24.0
3.0	2.0	12.1	1.9	14.7	1.8	20.1	1.6	17.5	1.6	20.2	1.7	28.5	1.6	20.7	1.6	23.4	1.7	32.0	1.5	22.0	1.5	24.4	1.5	29.6	1.5	25.1	1.5	27.5	1.5	32.7
3.5	2.2	14.7	2.2	19.7	2.1	27.3	1.9	22.5	1.9	26.3	1.9	34.2	1.9	26.3	1.9	30.1	1.9	38.1	1.7	26.0	1.7	29.1	1.8	38.8	1.7	29.4	1.7	32.6	1.8	42.6
4% Slope																														
1.5	1.1	3.7	1.1	5.0	1.0	6.4	0.9	8.0	0.9	8.9	0.9	11.0	0.9	9.9	0.9	10.8	0.9	13.0	0.8	10.2	0.8	11.2	0.8	12.8	0.8	11.9	0.8	12.7	0.8	14.6
2.0	1.4	6.0	1.4	8.1	1.3	10.7	1.2	11.8	1.2	13.4	1.2	16.9	1.2	14.2	1.2	15.9	1.2	19.5	1.0	13.3	1.0	14.5	1.1	19.6	1.0	15.4	1.0	16.7	1.1	22.1
2.5	1.7	8.8	1.7	11.9	1.6	16.3	1.4	14.5	1.4	16.7	1.4	21.5	1.4	17.4	1.4	19.7	1.4	24.5	1.2	16.7	1.2	18.4	1.3	24.8	1.2	19.2	1.2	20.9	1.3	27.7
3.0	2.0	12.2	2.0	16.4	1.9	22.9	1.7	19.2	1.7	22.4	1.8	32.1	1.7	22.7	1.7	25.9	1.8	36.0	1.5	22.2	1.5	24.8	1.6	33.5	1.5	25.3	1.5	27.9	1.6	37.0
3.5	2.3	16.1	2.3	21.7	2.2	30.7	1.9	22.6	2.0	28.8	2.1	41.5	1.9	28.5	2.0	32.9	2.1	46.0	1.7	26.2	1.7	29.5	1.8	41.5	1.7	29.7	1.7	33.0	1.8	43.9
5% Slope																														
1.5	1.2	4.4	1.2	6.0	1.1	8.0	0.9	8.1	0.9	9.1	0.9	11.4	0.9	10.0	0.9	11.1	0.9	13.5	0.8	10.4	0.8	11.3	0.8	13.4	0.8	12.1	0.8	16.8	0.8	15.4
2.0	1.5	6.9	1.5	9.4	1.4	12.9	1.2	11.9	1.2	13.6	1.2	17.5	1.2	14.4	1.2	16.2	1.2	20.3	1.1	15.2	1.1	16.8	1.1	20.5	1.1	17.5	1.1	19.2	1.1	23.1
2.5	1.8	10.0	1.7	12.1	1.6	16.8	1.4	14.7	1.4	17.0	1.5	24.8	1.4	17.6	1.4	20.0	1.5	28.2	1.3	18.7	1.3	20.9	1.4	28.7	1.3	21.4	1.3	23.7	1.4	31.9
3.0	2.1	13.5	2.1	18.4	2.0	26.4	1.7	19.4	1.7	22.8	1.9	36.4	1.7	22.9	1.7	26.4	1.9	40.7	1.6	24.4	1.6	27.6	1.7	38.8	1.6	27.8	1.6	31.0	1.7	41.0
3.5	2.3	16.3	2.3	22.1	2.3	34.8	2.0	24.6	2.1	31.6	2.2	46.5	2.0	28.8	2.1	36.0	2.2	51.4	1.8	28.6	1.8	32.5	1.9	45.0	1.8	32.3	1.8	36.4	1.9	49.4
6% Slope																														
1.5	1.2	4.5	1.2	6.1	1.2	9.9	1.0	9.4	1.0	10.8	1,0	14.0	1.0	11.5	1.0	13.0	1.0	16.5	0.9	12.1	0.9	13.4	0.9	16.5	0.9	14.1	0.9	15.5	0.9	18.9
2.0	1.5	7.0	1.5	9.5	1.5	15.5	1.3	13.4	1.3	15.6	1.3	20.8	1.3	16.2	1.3	18.5	1.3	24.0	1.2	17.2	1.2	19.2	1.2	24.3	1.2	19.8	1.2	21.9	1.2	27.3
2.5	1.8	10.1	1.8	13.8	1.7	19.9	1.5	16.4	1.5	19.2	1.6	29.2	1.5	19.6	1.5	22.5	1.6	32.7	1.4	20.8	1.4	23.6	1.5	33.3	1.4	23.9	1.4	26.7	1.5	37.0
3.0	2.1	13.7	2.1	18.7	2.0	27.5	1.8	21.3	1.9	27.6	2.0	41.5	1.8	25.1	1.9	31.7	2.0	46.3	1.7	26.8	1.7	30.7	1.8	43.6	1.7	30.5	1.7	34.5	1.8	48.0
3.5	2.4	17.9	2.4	24.5	2.4	39.6	2.1	26.8	2.2	34.7	2.3	52.4	2.1	31.2	2.2	39.5	2.3	57.9	1.9	31.1	1.9	35.9	2.0	51.1	1.9	35.2	1.9	40.1	2.0	56.0

The cut and fill has been balanced in the above table for the various side slopes, top width of 4' and 3:1 backslope including 0.5' freeboard. Table to be used in connection with "Diversion Terrace Design Table" for determining the centerline depth of cut to give required dirt in the ridge.

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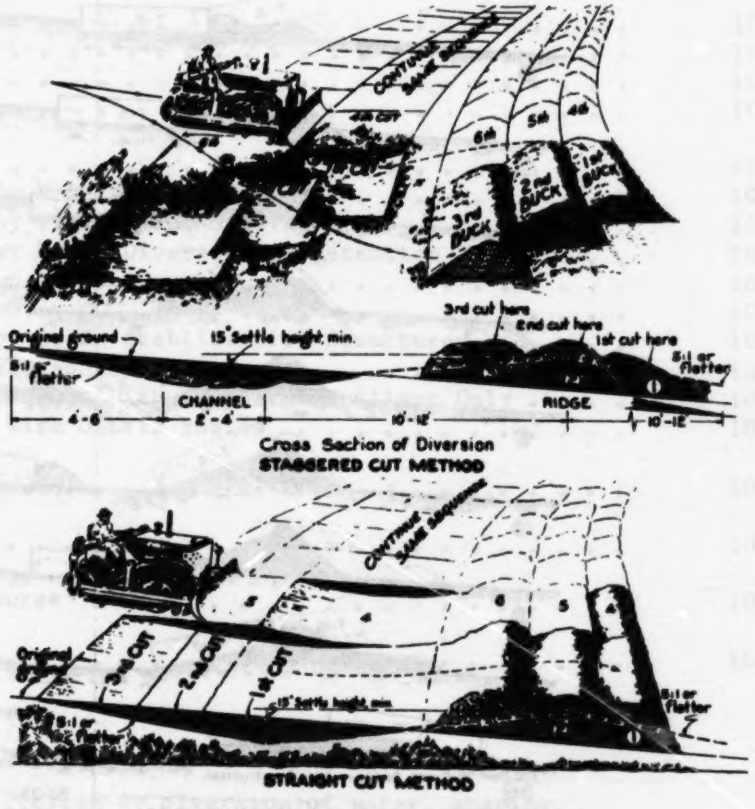
Exhibit 9-6 Centerline depth of cut and area of excavation for trapezoidal and V section diversions

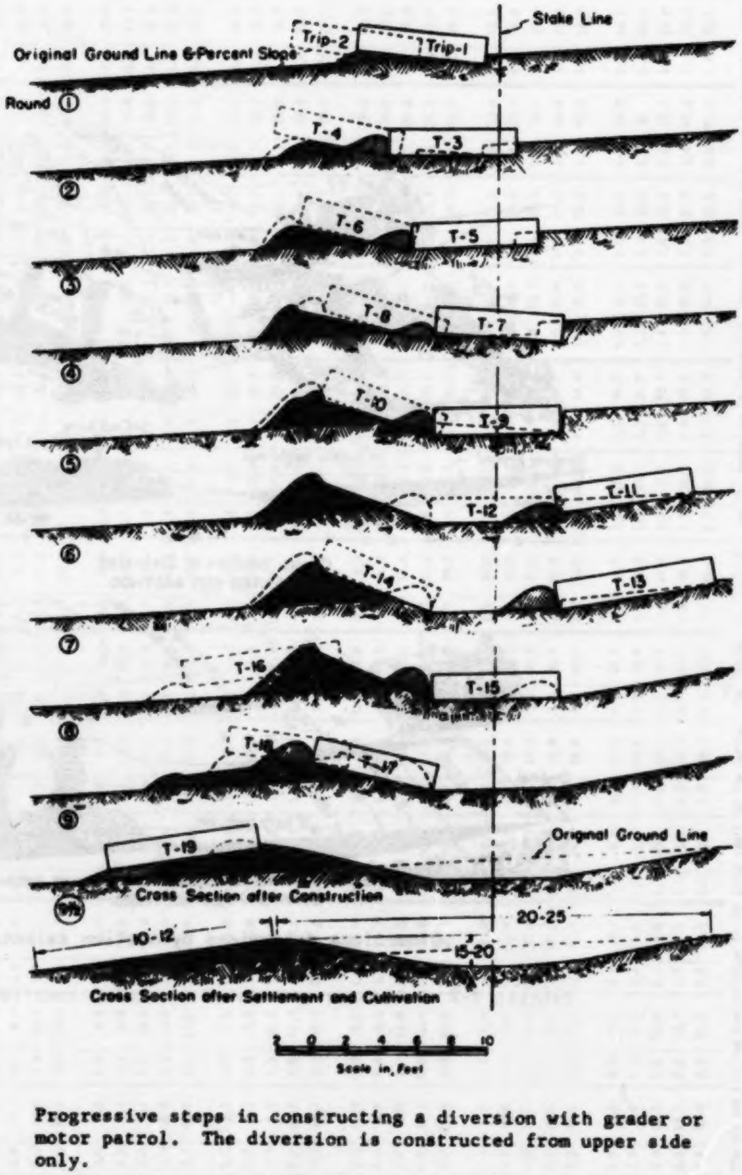

CONTINUE SAME SEQUENCE
1st BUCK
2nd BUCK
3rd BUCK
4th
5th
6th
3rd cut here
2nd cut here
1st cut here
Original ground
15' Settle height min.
5:1 or flatter
CHANNEL
RIDGE
4'-6'
2'-4'
10'-12'
10'-12'
1st CUT
2nd CUT
3rd CUT
4
5
6

Cross Section of Diversion
STAGGERED CUT METHOD

STRAIGHT CUT METHOD

Dimensions determined by section selected.

Exhibit 9-7 Bulldozer methods of diversion construction


Stake Line
Trip-2
Trip-1
Original Ground Line 6 Percent Slope
Round ①
T-4
T-3
②
T-6
T-5
③
T-8
T-7
④
T-10
T-9
⑤
T-12
T-11
⑥
T-14
T-13
⑦
T-16
T-15
⑧
T-18
T-17
⑨
T-19
Original Ground Line
Cross Section after Construction
9½
20'-25'
10'-12'
15-20'
Cross Section after Settlement and Cultivation
2 0 2 4 6 8 10
Scale in Feet

Progressive steps in constructing a diversion with grader or motor patrol. The diversion is constructed from upper side only.

Exhibit 9-8 Grader method of diversion construction

ENGINEERING FIELD MANUAL

CHAPTER 10. GULLY TREATMENT

Compiled by: Allyn C. Bennett, Engineering Specialist, SCS, Temple, Texas

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  - Gully Treatment by Filling and Shaping 10-5
  - Gully Treatment by Water Diversion or Retention 10-5
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Figures

Figure 10-1 Gully treated by diversion of water, shaping, and fencing to exclude grazing 10-4
Figure 10-2 Gully treated by filling, shaping and planting to grass 10-6
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ENGINEERING FIELD MANUAL

CHAPTER 10. GULLY TREATMENT

1. GENERAL

DEFINITION

Gully treatment is the stabilization of active gullies by vegetative or structural measures or a combination thereof.

INTRODUCTION

Gullies can be prevented by such measures as increasing the absorptive capacity of the soil, protecting the land surface and natural drainageways from erosion, and by conducting surface runoff water from fields at a non-erosive velocity through properly prepared and maintained waterways.

Besides ruining fertile land, gullies interfere with farm operations, undermine farm improvements, encroach on public highways, endanger livestock, and often mar the beauty and lower the market value of a farm. Materials eroded from gullies reduce the capacity of reservoirs, natural streams, and drainage channels, and cover bottom lands with deposits of infertile soil.

CAUSES

Gullies are caused by runoff water cutting, or collecting in, surface depressions and flowing at a velocity sufficient to detach and carry away soil particles. The power to erode increases as the stream increases in size, velocity, and duration. If the depression or drainageway is not protected from erosion a gully will form and be enlarged by each flow through it. Many large gullies have formed because simple steps were not taken to stop them in the beginning.

Drainageways which collect runoff water may be natural or may have been caused by:

1. Improperly located farm roads, field and access roads, and trails.
2. Livestock trails.
3. Up-and-down slope cultivation.
4. Unprotected terrace outlets and waterways.
5. Unrepaired breaks in terraces and diversions.
6. Excavated drainage or diversion channels without needed vegetative or structural protection.

7. Rilling on bare slopes.
8. Improperly designed and placed road drainage structures.
9. Built-up fence rows or property boundaries.
10. Improper land use.
11. Toxic wastes that destroy vegetation.

It is important that the technician be acquainted with those practices and conditions that are likely to start gullying. This will enable him to assist the landowner in selecting land use changes and cultural measures which will prevent further erosion and help to control existing gullies.

2. PLANNING

Gully control can best be attained through a plan that takes into account the treatment of the watershed draining into the gully, as well as treatment of the gully itself. A conservation plan for, or the conservation treatment of, any piece of land should consider all needed and feasible gully stabilization work. The plan may include such practices as critical area plantings, grassed waterways or outlets, grade stabilization structures, diversions, and debris basins. These may be used singly or in combination with other practices to accomplish the following:

1. Interception of runoff water above the gullied area with a diversion or terraces.
2. Retention of runoff water on the drainage area by tillage practices, vegetation and structures.
3. Elimination of the gully by filling and shaping the drainageway with earth-moving equipment for critical area planting or grassed waterway development.
4. Revegetation, either by natural processes or by critical area planting and grassed waterway development.
5. Construction of grade stabilization structures to control the grade of the gully and detain or impound water.
6. Complete exclusion of livestock.
7. Control of sediment from active gullies with debris basins.
8. Drainage of seep areas where gully banks are unstable.

GULLY TREATMENT BY VEGETATIVE MEANS

The objective of most gully control work is to stabilize the gully surfaces by vegetative means. All other measures should lead to that objective, except in areas where rainfall is too low to support a good grass cover.

Any gully, regardless of its size or condition, usually will regain a cover of natural vegetation if it is properly protected and is in an area where vegetation will grow readily. Diversion or retention of the water which causes the gully, protection from grazing or trampling by livestock, protection from fire, and the removal of other causes of disturbance usually result in growth of natural vegetation which will, in time, cover the gully and heal the erosion scars. (See Figure 10-1.)

Nearly all structural measures used, particularly in grassland areas, depend upon vegetation to support them and to stabilize the soil exposed to excessive runoff. Of first importance in revegetation is the exclusion of livestock or mechanical disturbance from the gullied area.

Most gullied areas or gully banks are not in good condition for vegetative growth since the fertile topsoil has been washed away, slopes are steep, and the battering of raindrops on the unprotected soil has produced conditions adverse to plant survival. Bank sloping may be necessary before vegetation can be expected to do an adequate job of gully stabilization.

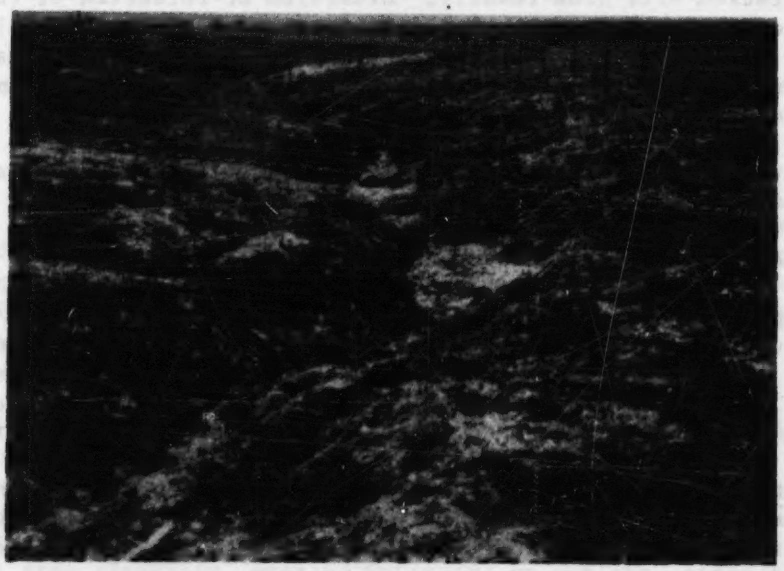
Adapted grasses, trees, shrubs, or vines provide good protection to gullied areas planned for critical area planting. The possible uses of the area after stabilization will determine the type of vegetation to be established.

A stabilized gully may be used as a grassed waterway for terrace outlets, a wildlife habitat, a woodland area or pasture. It should not be cultivated, burned, or used in a way that will weaken or destroy the reestablished vegetation. The best possible use should be selected after considering the size of the gully, its location with respect to other land uses on the farm, the control measures needed, and the type of maintenance required.

If it is to be used for a grassed waterway, the gully should be shaped to proper size and proportion. Erosion-resistance grasses should be well established before any terraces are constructed to empty into the channel. Trees, vines and shrubs ordinarily are not used in waterways unless the amounts of water flowing through the channel are relatively small and of infrequent occurrence.

Critical area planting of a gullied area in pastureland will be affected by the intensity of grazing on the area. Limited grazing of a grass vegetation during the establishment stage is often beneficial in controlling competitive weeds and shrubs. Overgrazing will seriously hinder establishment. Gullied areas in pastures might be better protected permanently from all grazing and retained for wildlife use after planting with grasses, shrubs, vines or trees suitable for wildlife habitat. In wooded or gullied areas adjacent to woods, it is desirable to plant trees of an adapted species and use the area as protected woodland.

In gullied areas where erosion is less critical, the slowest but cheapest method of gully control is protection from disturbance. Good results may be obtained and heavy expense avoided by the simple process of fencing the area to exclude grazing or cultivation.



Gully caused by concentrated runoff in overgrazed pasture

Figure 10-1 Gully treated by diversion of water, shaping and fencing to exclude grazing

GULLY TREATMENT BY FILLING AND SHAPING

Elimination of the gully or critically gullied area by filling and shaping may be the most practical or feasible means of treatment in preparation for critical area planting or grassed waterway development (see Figures 10-2 and 10-3). When this method of treatment is used, the gully or gullied area is shaped and smoothed so that the area can be established to vegetation and maintained with regular farm equipment. Where practical, the gully should be reshaped to provide stable velocities and other desirable hydraulic characteristics. See Chapter 7 of this manual.

During the filling process, the soil worked into the gully should be compacted since uncompacted material offers little resistance to erosion. It is best to fill field gullies during the time of year that a close-growing crop may be seeded immediately on the disturbed area to protect it from washing. Piecemeal filling or shaping should be discouraged since the partial blocking of the waterway often causes overfalls and increased gully erosion, and more land and soil may be lost than if the gully were untreated.

GULLY TREATMENT BY WATER DIVERSION OR RETENTION

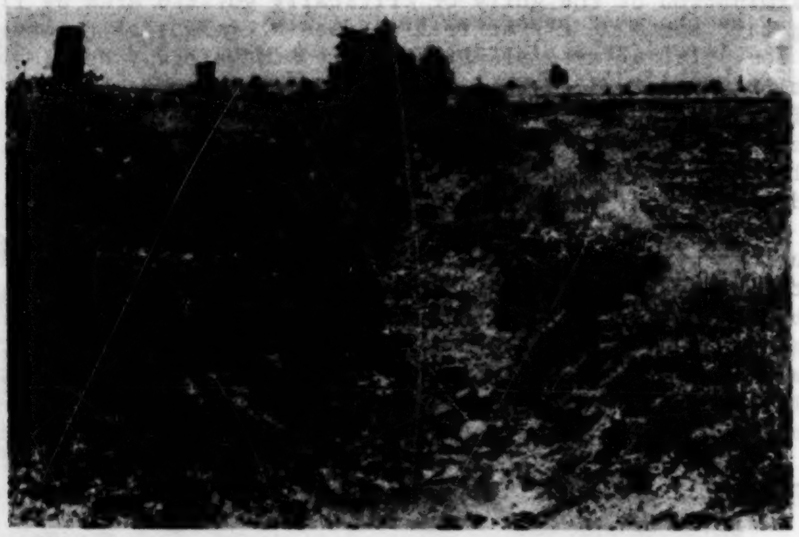
Reduction of the runoff which flows through a gully is one of the most effective control measures. This may be accomplised by diverting all or most of the runoff to a protected outlet or by holding excess rainfall on the land in the drainage area. Where these methods are feasible, they should be installed before other needed control measures are attempted within the gully.

Water Diversion

Care should be given to the disposal of the diverted water. Where it is not possible to empty a diversion onto a smooth, well-vegetated area or into a protected outlet, the water should not be diverted; otherwise, the diverted runoff may cause gullying in the disposal area. It may be possible to divert water from a number of gully heads to a common location and install a single, more economical stabilizing structure.

Diversions usually are constructed from the upper side in order to provide a wide channel section and easier construction. Diversions constructed adjacent to a gully or at the head of a gully overfall should be located away from the edge of the gully a distance equal to at least three times the depth of the gully. This will provide space for the gully banks to slough and stabilize, or to be shaped, without endangering the diversion.

Where a small gully has started on an area of thin vegetation in pastureland, it is often possible to stop head cutting by constructing an eyebrow-shaped ridge above the gully head with the ends of the ridge leading slightly downslope onto good grass cover. This is a temporary measure and requires considerable skill and care in the selection of outlet areas. Prompt application of revegetative measures in the gully should follow this practice.



Gully caused by emptying terraces into an unprotected outlet

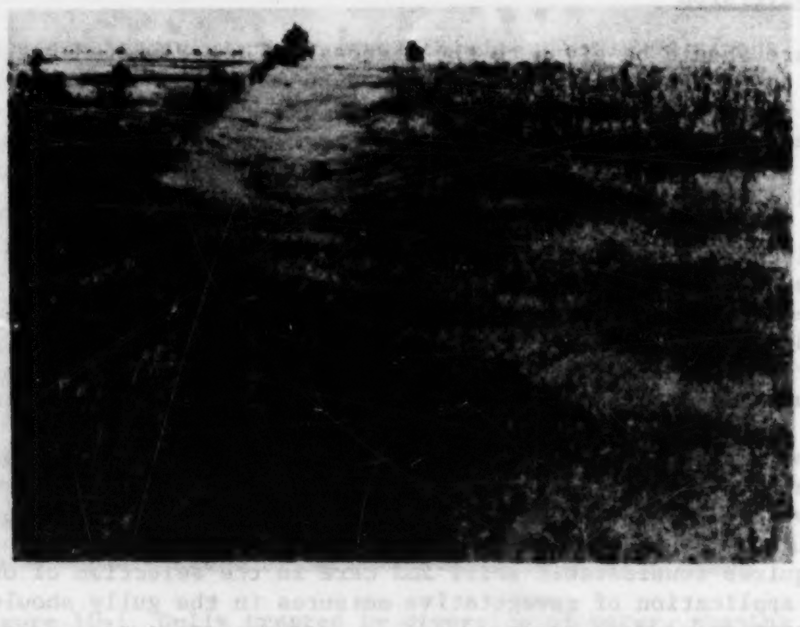


Figure 10-2 Same gully treated by filling, shaping and planting to grass

Gullied area

Reshaped and plowed before seeding native grasses

Fenced to exclude or control grazing

Figure 10-3 Critical area planting

Water Retention

Proper land use and conservation cropping and tillage practices are the first steps in holding water on the drainage area of a gully. These can be supplemented, as necessary and feasible, by other water-holding measures to further reduce the runoff into the gully. Some of these measures are discussed in the following paragraphs.

Level impounding terraces provide storage and can be farmed where cropland is involved in the drainage area of the gully. The ends may be left partially open, if necessary to drain part of the water from the terrace channel to prevent drowning out of crops or pasture vegetation. If level terraces are to retain all of the runoff, they should be constructed only on permeable soils and mild slopes.

Runoff water often can be prevented from entering or flowing through relatively large gullies by the use of carefully located earthen dams.

Selection of the damsite and elevation of the spillway are very important. The dam should be located near enough below the gully head that the channel gradient will be lowered to a slope that will stop the headward extension of the gully. The site should provide enough natural storage so that the emergency spillway will not flow often. Generally, a principal spillway or trickle tube is needed to reduce frequency and duration of emergency spillway flow.

In many areas where gullies are formed by runoff from small drainage areas, small earth dams are used to stop headward cutting and to furnish temporary stock water after periods of rainfall. Such structures, however, give better protection if equipped with a drop inlet that will slowly release the impounded runoff water and provide storage space for runoff from succeeding rains. Since there will be only occasional spillway discharge, vegetative practices and natural reproduction of native vegetation below the fill will have an opportunity to control the gully at little cost.

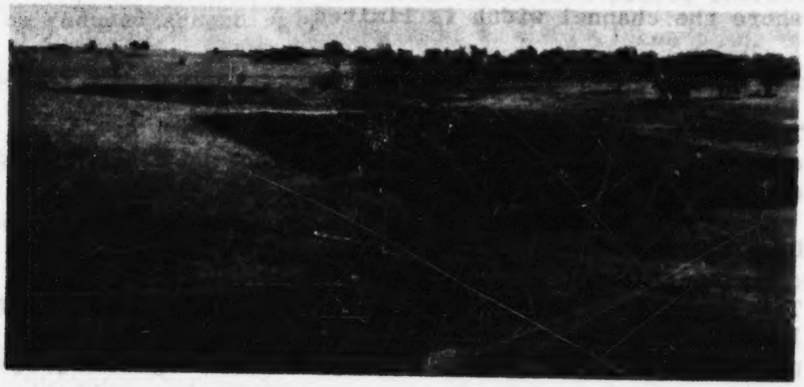
The two types of earth dam structures described above usually are designed as grade stabilization structures which are discussed later in this chapter.

GULLY TREATMENT BY GRADE STABILIZATION STRUCTURES

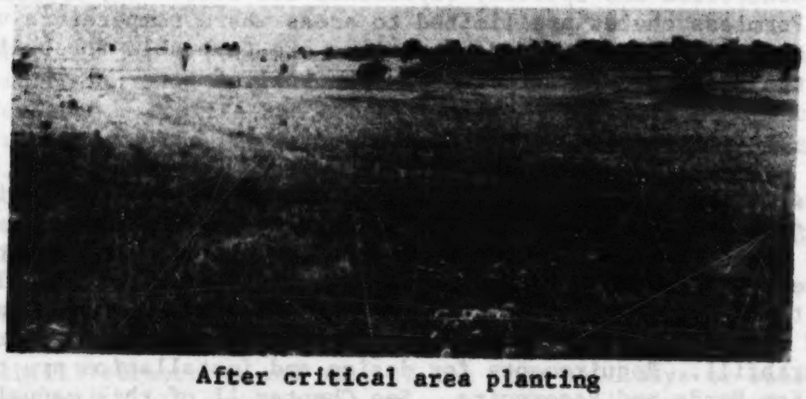
It is not always possible to keep runoff water out of gullies by retaining or diverting it, and the runoff must flow through the gully channel. To do this safely may require that both vegetation and structures (see Figure 10-4) be planned and established in the gully at critical points.

Planning gully treatment under these conditions may require that the gradient of the channel be reduced so that water will travel at a nonerosive velocity. Some type of structure may be required at overfalls, abrupt changes in gradient, entrances of branch gullies or at other critical points to supplement vegetation in stabilizing the channel gradient.

Original gullied area



After installing drop inlet structure for grade control, and shaping



After critical area planting

Figure 10-4 Gullied area treated by using drop inlet structure along with shaping and critical area planting

Structural Measures

Structural measures should be used for gully control only when other measures are not applicable or adequate. The following types of structural measures are used in gully control work. (See Chapter 6 of this manual for technical information and design requirements.)

1. Straight drop spillway

   This type of structure is generally used in the lower reaches of water disposal systems, such as terraces, diversions, outlets, and waterways; for large overfalls adjacent to streams; or for drainage.

2. Box inlet drop spillway

   This type of structure has the same general usage as the straight drop spillway but is better adapted to larger flows and sites where the channel width is limited.

3. Hood inlet spillway

   This structure uses a straight-pipe principal spillway, usually on a steep slope, in an earth embankment to control head cutting or to safely drop water to a lower level.

4. Drop inlet spillway

   This type of structure has the same general usage as the hood inlet and has the added advantages of permitting drainage of the pond or fluctuating the water level for management purposes.

5. Chute spillways

   This structure is sometimes used where the head or drop to be controlled and spillway capacities are relatively small. Formless chutes are limited to areas where temperature variations are moderate and conditions are favorable for building the shape of the structure in the soil.

Earthfill Structures with Vegetated Spillway Only

These may be used as grade stabilization structures and to impound sediment or water for gully treatment. They may also provide temporary livestock water or be used as debris basins. This type has limited use since a vegetated spillway stable enough to withstand frequent flows through it can seldom be found in the right location in gullied areas. Vegetated spillways occasionally can be developed prior to construction of the earthfill. Requirements for design and installation are the same as those for Ponds and Reservoirs. See Chapter 11 of this manual.

SEDIMENT CONTROL WITH DEBRIS BASINS

Debris basins are used where physical conditions or landownership prevent the treatment of the sediment source by the installation of gully control measures.

This type of structure is a dam, usually equipped with a pipe principal spillway, constructed across a waterway or at some other suitable location to form a sediment storage basin. A debris basin is used to preserve the capacity of reservoirs, ditches, canals, diversions, waterways or streams and to prevent undesirable deposition on bottom lands. This is done by storing a high percentage of the sediment and other debris moving from the drainage area.

The capacity of a debris basin is governed by the volume of sediment expected to be trapped at the site during the planned useful life of the structure or the improvements it is designed to protect. Where it is assured that periodic removal of debris will take place, the design capacity may be reduced accordingly.

Usually, the design, layout and construction principles for debris basins are identical to those for principal spillway-type grade stabilization structures or farm ponds. Only the primary purpose of the structure may differ. Therefore, previous discussions in this chapter or in Chapter 11 of this manual will apply, depending upon type of debris basin being considered.

For further guidance on construction and construction materials, see Chapter 17 of this manual.

3. SURVEYS

Surveys should be adequate to determine the gradient and cross sections of gullies to be treated with vegetation alone or in combination with filling and shaping. In many cases hand level data will be satisfactory.

A thorough field survey of site locations should be made for grade stabilization structures so that the most economical type of structure can be designed. Profile and cross-section surveys are needed to show the characteristics of the watercourse above and below the planned structure location. The structure may affect the flow of water for quite a distance above and below its proposed site, or have an effect on other structures. Topographic and soils information as well as a geologic investigation may be needed on the structure site itself for detailed designing. Decisions on these surveys should be made in the field based on the type of structure being considered.

Earthfill structures and some of the drop spillways or chutes may need additional field surveys for an emergency spillway. Profile and cross-section surveys of the proposed spillway sites may be needed for a design that provides adequate capacities at nonerosive velocities.

Field surveys should also record the location, pertinent elevations, and sizes of any bridges, culverts, fence lines, buildings, etc., which might influence the design of the structure. Determinations must be made as to the size and shape of the watershed and all other factors that influence runoff and the design of the structure. (See Figure 10-5, Gully survey example.)

4. DESIGN GUIDELINES

Guidance in the design of gully treatment measures will be found in Chapter 6 - Structures, Chapter 7 - Waterways, Chapter 8 - Terraces, Chapter 9 - Diversions, and Chapter 11 - Ponds and Reservoirs.

A permanent grade stabilization structure must have a stable downstream grade with no degrading after the protective measures are established. Any excess grade should be compensated for in the structure design by lowering the apron floor or adding other structures in the channel below. If topography permits, the drop inlet is more suitable than an overfall structure where there is excess grade below the structure location.

The type of structure and the site selection will be influenced to some extent by the availability of materials. For example, if a drop inlet structure is being considered, suitable core and fill material should be readily available. Available rock suitable for a rubble masonry structure may be the deciding factor on the type of drop spillway to construct.

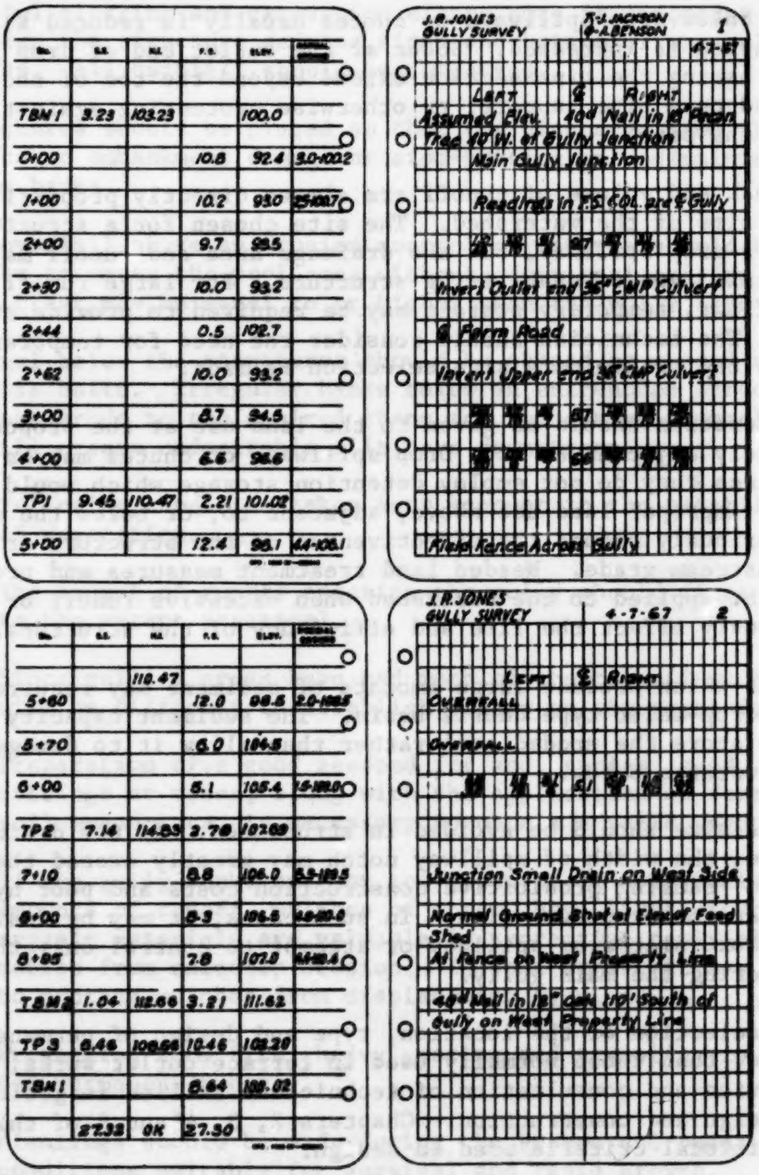
The type of foundation for any proposed site may determine the type and size of structure to be constructed. Wet, seepy foundations are not suitable for large concrete structures unless the design includes expensive corrective measures. This may be the place where a drop inlet structure is needed. Dry, unstratified foundations are suitable for almost any type of structure. Where there are wet areas on the structure site, drop spillways or chutes can be constructed in a drier area and the waterflow diverted to them.

When the structure is to control a gully head or overfall, the site selection should be carefully made. The crest of any erosion control structure should be set at an elevation which anticipates the upstream movement of the gully head during the healing period.

The location for a suitable emergency spillway is another important factor in selecting a site for any erosion control or detention dam where part of the flow is carried through the dam by a principal spillway. In some cases, drop spillways will need an emergency spillway to help carry the less frequent peak flows around the end of the embankment. Therefore, site selection and design should include full consideration of this important feature.

Scour at the outlet is one of the important factors leading to failure of an overfall structure. Scour may be controlled by giving proper consideration in the design to the:

1. Stability of the grade below the structure.



Sta.	B.S.	H.I.	F.S.	Elev.	[illegible]
TBM 1	3.23	103.23		100.0	
0+00			10.8	92.4	3.0-100.2
1+00			10.2	93.0	2.5-100.7
2+00			9.7	93.5	
2+30			10.0	93.2	
2+44			0.5	102.7	
2+62			10.0	93.2	
3+00			8.7	94.5	
4+00			6.6	96.6	
TP1	9.45	110.47	2.21	101.02	
5+00			12.4	98.1	4.4-106.1

J.R.JONES
GULLY SURVEY
T-J.JACKSON
Φ-A.BENSON
1
4-7-67

Left ℄ Right
Assumed Elev. 40d Nail in 18" Pecan Tree 40' W. of Gully Junction
Main Gully Junction
Readings in F.S. COL. are ℄ Gully
Invert Outlet end 36" CMP Culvert
℄ Farm Road
Invert Upper end 36" CMP Culvert
Field Fence Across Gully

Sta.	B.S.	H.I.	F.S.	Elev.	[illegible]
		110.47			
5+60			12.0	98.5	2.0-108.5
5+70			6.0	104.5	
6+00			5.1	105.4	[illegible]
TP2	7.14	114.83	2.78	107.69	
7+10			8.8	106.0	[illegible]
8+00			8.3	106.5	[illegible]
8+85			7.8	107.0	[illegible]
TBM2	1.04	112.66	3.21	111.62	
TP3	6.46	108.66	10.46	102.20	
TBM1			8.64	100.02	
	27.32	OK	27.30		

J.R.JONES
GULLY SURVEY
4-7-67
2

Left ℄ Right
OVERFALL
OVERFALL
Junction Small Drain on West Side
Normal Ground Shot at Elev. of Feed Shed
At fence on West Property Line
40d Nail in 18" Oak 110' South of Gully on West Property Line

Figure 10-5 Gully survey example

(See cover sheet and sketch map example in Chapter 1 of this manual.)

2. Velocities occurring in the downstream channel.

3. Tailwater elevations for different flow stages.

4. Dissipation of water energy in the outlet.

Scour below drop spillways or chutes usually is reduced as the tailwater elevation is increased. Scour at the outlet end of drop inlets is reduced by having the pipe section extend beyond the toe of the fill and cantilevered on a pipe support, or otherwise protecting against undercutting of the pipe.

The peak and volume of runoff are almost directly proportional to the length and size of the watershed. The site chosen for a structure may be adapted to a drop spillway, but the drainage area and runoff may be too large for this type of stabilizing structure. For large runoff volumes or high peak flows, temporary storage may be required to provide an economical discharge. The technician should consider the need for temporary storage at the time the preliminary site selection is made.

Consideration should be given to the land use at the proposed site or immediately adjacent to it. Drop spillways or chutes may be placed in cropland since they do not employ detention storage which would be lost by siltation. Improper land use above, adjacent to, or below the structure site may seriously reduce the effectiveness of the structure or stability of the downstream grade. Needed land treatment measures and proper land use should be applied to the watershed when excessive runoff or siltation would seriously affect the life and efficiency of the structure.

Gullies which produce large amounts of sediment may require an earth dam with a drop-inlet type debris basin. The sediment capacity should be designed to store the eroded soil rather than allow it to damage valuable land or structures below.

Extreme size should be avoided in structures. If the drainage area is too large, the width of spillway notch may greatly exceed the width of the channel, causing prohibitive construction costs and poor hydraulic conditions at the structure site. In such cases, it may be desirable to consider a box inlet drop spillway or attempt to control only the lateral gullies entering the main gully.

Final selection of the location, type and design of permanent structures, larger than those normally used in terrace outlet works, should be with the advice and consultation of technicians skilled in geology, hydrology, design and construction. Chapters 2, 3, 4 and 6 of this manual include additional criteria used in design.

5. INSTALLATION OF MEASURES

Chapter 17 of this manual describes surveys for setting line and grade stakes for construction of the various structures.

Careful clearing and excavation of the site is important since the ties between the structure and the sides and bottom of the gully are points of weakness. All backfill should be compacted.

Structures should be placed so that the discharge from the spillways will not cause embankment damage or side-cutting or undermining of the downstream banks.

Any overfall above an erosion control structures should be sloped to allow water to enter the pool area without additional erosion, even though the inlet crest may be equal to or higher than the gully head elevation.

Channel below the structures should be shaped as needed when the structure is built. Irregular banks below an entrenched structural spillway will not erode to the desired shape for the outlet channel, and the erosion will create undesirable silt bars downstream.

The following should be taken into account in the establishment of any type of vegetation.

1. The amount of runoff entering the gully should first be reduced to the extent practical.

2. Since gullied areas have had much of the topsoil washed away, it will be difficult to establish plants on the remaining subsoil.

3. Preparation of a good seedbed for sod, sprigs, seed, small plants, cuttings or vines, along with the application of fertilizer and soil amendments, is necessary to obtain a rapid vegetative growth.

4. If the gully banks are not too steep or do not receive large amounts of runoff, mulches of straw, hay, light brush or other organic materials are valuable in protecting newly planted vegetation from raindrop erosion. In some areas, it may be necessary to protect mulches from displacement by winds.

5. Protection from fire, heavy grazing and trampling is important for permanent control.

6. Plantings should be made during the season and under climatic conditions suitable for survival and rapid growth.

7. Maintenance of vegetative cover is as important as the original establishment of the cover.

8. A strip of grass of variable width around the gullied area should be included in the planting area to insure control of the area and to protect the more slowly established plantings in the severely damaged area. Where the gully lies in or adjacent to a cultivated field, a strip of vegetation at least 25 feet wide should be established and maintained next to the gully banks.

9. Areas that tend to remain wet may require tile drains to maintain favorable conditions for growth of vegetation.

6. MAINTENANCE

Periodic checks should be made of all gully control works. The following maintenance practices are important:

1. Protect all vegetative plantings from grazing until established and then allow only limited use.

2. Eliminate competition from undesirable weeds and grasses in vegetative plantings.

3. Protect all plantings from trampling and fire.

4. Make immediate repairs of breaks or low spots in terraces, diversions or structures.

5. Remove trash from drop inlets or weirs.

6. Sod or seed spot failures in vegetative plantings. Fertilize vegetation as required.

7. Mow or properly graze waterway areas.

8. Inspect sides, corners and wingwalls of all structures and repair cracks in earth caused by settling, rodent burrows, dry weather, etc., before the structure is weakened.

Considerable damage, as well as loss of structures may result from failure to protect and maintain the structures properly. Providing minor maintenance in a timely manner often saves costly repair jobs when an unusual storm occurs.

ENGINEERING FIELD MANUAL

CHAPTER 11. PONDS AND RESERVOIRS

Compiled by: George M. Renfro, Agricultural Engineer, SCS, Fort Worth, Tex.

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ENGINEERING FIELD MANUAL

CHAPTER 11. PONDS AND RESERVOIRS

PART I - GENERAL

1. DEFINITION

Ponds and reservoirs are bodies of water created by constructing a dam or embankment across a watercourse or by excavating a pit or dugout. Ponds constructed by the first of these methods are referred to hereinafter as "Embankment Ponds" and those constructed by the latter method as "Excavated Ponds." Ponds resulting from both excavation and embankment are classified as Embankment Ponds where the depth of water impounded against the embankment at emergency spillway elevation is 3 feet or more.

2. USES FOR WATER ON THE FARM

WATER FOR LIVESTOCK

Water is as important as forage in the production of livestock. Inadequate stock water developments in pasture and range areas contribute to an unstable livestock industry and livestock losses, prevent use of needed grazing areas, and encourage overgrazing in the vicinity of existing water supplies.

Providing adequate water for livestock on range and pasture consists of developing enough water to satisfy stock needs and providing a proper distribution in relation to the available forage.

A pond should be of a size that will meet the needs of all livestock that will use the surrounding grazing area. Table 11-1, showing the average daily consumption of water by various kinds of lifestock, should be helpful in estimating water needs.

Table 11-1. Daily consumption of water by livestock

Kind of Livestock	Gallons per Head per Day
Beef Cattle and Horses	12-15
Dairy Cows (drinking only)	15
Dairy Cows (drinking and barn needs)	35
Hogs	4
Sheep	2

The total amount of water that will be consumed at one pond will depend on the average daily consumption per animal, the number of livestock served, and the length of period over which they are served.

IRRIGATION STORAGE

The required storage capacity of a farm reservoir used for irrigation depends on a number of factors. These are the water requirements of the crops to be irrigated, the effective rainfall that can be expected during the growing season, the application efficiency of the irrigation method used, the losses due to evaporation and seepage, and the expected inflow into the pond. All of these can be estimated with reasonable accuracy and a water budget prepared to determine the required capacity of the reservoir.

Where the acreages to be irrigated and the storage requirements are small, the preparation of water budgets is often not justified. In such cases, Table 11-2, or locally developed guides, can be used to determine storage requirements in small irrigation ponds and reservoirs.

Table 11-2. Capacity guide for small irrigation reservoirs 1/

Climate	Annual Rainfall Inches	Acre Feet per Acre Irrigated 2/		
		Vegetable Crops	Field Crops	Perennial Crops
Superhumid	Over 60	0.75	1.00	1.25
Humid	40 - 60	1.00	1.50	1.75
Subhumid - Moist	30 - 40	1.50	2.00	2.50
Subhumid - Dry	20 - 30	2.00	2.75	3.50
Semiarid	10 - 20	3.00	4.00	6.00
Arid	Under 10	Small reservoirs are not reliable		

1/ Based on the assumption that the watershed area is adequate to fill the reservoir at least once annually.
2/ Table is limited in use to 40 acres irrigated.

Where irrigated acreages are large the preparation of a water budget is required. In such cases the problem should be referred to an experienced engineer or hydrologist.

REGULATION OF IRRIGATION STREAMS

In some locations available irrigation streams fluctuate widely or become so small as to limit the method of application, reduce the efficiency of application, or require excessive amounts of labor. In such instances, on-farm regulating or "overnight storage" reservoirs may be constructed to regulate and increase the available irrigation stream. Reservoirs are filled by canal delivery, diversion, or pumping.

The regulating reservoir should be located where it will serve the largest acreage possible consistent with the available water supply. The capacity of such a reservoir will vary with the stream size to be regulated and the period of time it is to be stored. Storage of the available inflow for 24 to 72 hours is common.

FIELD AND ORCHARD SPRAYING

Ponds may provide water for applying insecticides and fungicides to field and orchard crops. The amount of water needed for spraying is relatively small, but it is important that it be available when needed. About 100 gallons per acre for each application should be enough for most field crops. Orchards, however, may require 1,000 gallons or more per acre for each spraying.

Suitable means should be provided to convey water from the pond to the spray tank. If the pond is of the embankment type, a pipe placed in the dam and equipped with a valve and a flexible hose at the downstream end will permit the spray tank to be filled by gravity. If the pond is the excavated type, a small pump will be required to fill the tank.

FISH PRODUCTION

A pond that is constructed and managed properly may yield from 100 to 300 pounds of fish annually for each acre of water surface. This is about equal to the beef production realized from average improved grassland.

Ponds with a surface of 1/4 acre to several acres can be managed for good fish production. Those less than two acres have proven popular since they are not as difficult to manage as the larger ones.

Shallow water at the edges of a pond promotes waterweed growth, which makes fish management difficult, and provides a breeding place for mosquitoes These problems can be overcome to a large extent by deepening the shallow edges around the pond. This can be done by borrowing from the pool edge during construction, or by cutting and filling as shown in Figure 11-1.

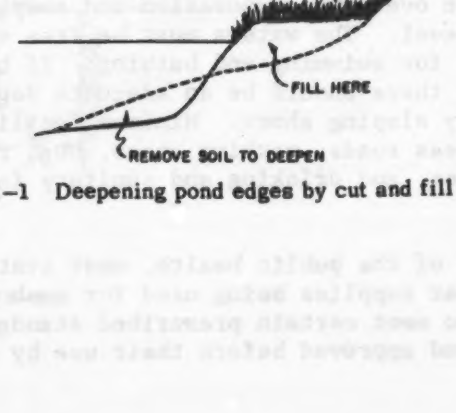


Figure 11–1 Deepening pond edges by cut and fill method

FIRE PROTECTION

The fire protection pond should be located reasonably near the buildings to be protected. A centrifugal pump with power unit attached and a length of hose sufficient to reach all sides of the farthest building should be provided. It is good practice in areas subject to freezing to provide for one or more dry hydrants similar to the one shown in Figure 11-2.

A satisfactory fire stream should not be less than 250 gallons per minute with a pressure at the nozzle of no less than 50 pounds per square inch. Fire nozzles usually range from 1 to 1½ inches in diameter. Good quality rubber-lined fire hose, 2½ to 3 inches in diameter, should be used. The length of the hose should preferably not exceed 600 feet.

A typical example of a fire hose line is one consisting of 500 feet of 3-inch hose to which a 1-1/8-inch smooth nozzle is attached. A centrifugal pump, operated at 85 p.s.i. will provide a stream of 265 g.p.m. with a nozzle pressure of 50 p.s.i. Such a stream running for 5 hours would require 1/4 acre foot of water. Local dealers in pumps, engines, and similar equipment should be able to furnish the data required regarding pump capacities and engine horsepower.

A fire protection pond may also serve as a source of supply for local fire departments when accessible to large tank trucks. These trucks are heavy with a maximum capacity of about 1,000 gallons. They normally carry about 20 feet of suction hose and generally must operate from all-weather roads. These points should be considered in location of dry hydrants. When used for this purpose, hydrant fittings should be designed to fit local fire company equipment. To make best use of these installations the fire department should be kept up to date on the location of installations accessible to their equipment.

RECREATION

A pond or reservoir can provide recreation, such as swimming, boating and fishing for the owner, his family, and friends. The area immediately surrounding the pond can be made into an attractive place for picnics and games.

Where a pond is used for public recreation, there should be a supply of water adequate to overcome evaporation and seepage losses and maintain a desirable water level. The waters must be free of pollution, especially where they are used for swimming and bathing. If bathing is one of the intended activities there should be an adequate depth of water in the vicinity of a gently sloping shore. Minimum facilities for public use and safety, such as access roads, parking areas, boat ramps or docks, fireplaces, picnic tables, and drinking and sanitary facilities, should be provided.

For protection of the public health, most states have laws and regulations governing water supplies being used for such purposes as bathing and human consumption to meet certain prescribed standards. Such supplies usually must be tested and approved before their use by the public is permitted.

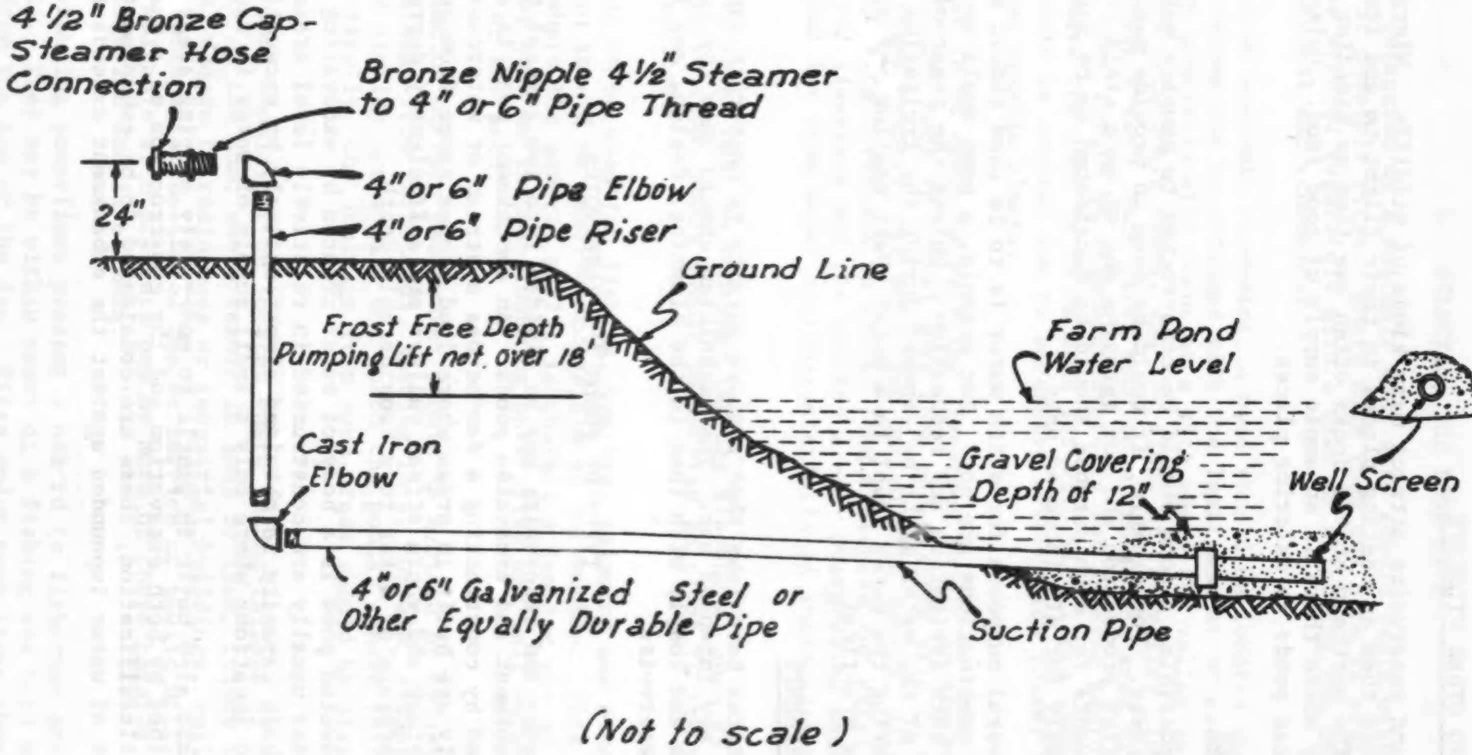

4 1/2" Bronze Cap-
Steamer Hose
Connection
Bronze Nipple 4 1/2" Steamer
to 4" or 6" Pipe Thread
24"
4" or 6" Pipe Elbow
4" or 6" Pipe Riser
Ground Line
Frost Free Depth
Pumping Lift not over 18'
Cast Iron
Elbow
Farm Pond
Water Level
Gravel Covering
Depth of 12"
Well Screen
4" or 6" Galvanized Steel or
Other Equally Durable Pipe
Suction Pipe
(Not to scale)

Figure 11–2 Details of dry hydrant installation.

WATERFOWL AND OTHER WILDLIFE

Ponds and reservoirs attract many kinds of wildlife. Migratory waterfowl often use them as resting places in their flight to and from the North. In some of the northern states ducks often use them as breeding places, particularly where there is an ample supply of good food. Upland game and game birds use ponds as watering places.

MULTIPLE USES

Where possible, a pond should be constructed to provide water for two or more purposes. For example, it could be used to provide water for livestock, for fish production and for spraying one or more field crops. Storage requirements for each purpose should be considered to be sure of an adequate supply for all intended uses.

The several purposes for which water is to be used should be compatible. Some combinations are not. For example, a pond would not normally be used for both irrigation and recreation. Unless the reservoir is very large, most of the water might be removed during the irrigation season, thereby lowering the water level to a point where boating and swimming would not be practical.

LEGAL REQUIREMENTS

Many states have laws that require permits to construct dams for water storage for any intended use. The technician should know the requirements in his state and comply with them in the planning, design, and layout of ponds and reservoirs.

3. TYPES OF PONDS AND RESERVOIRS

Farm ponds and reservoirs may be divided into two general types; namely, embankment and excavated ponds. An embankment pond is a body of water created by constructing a dam across a stream or watercourse. These ponds usually are built in areas where land slopes range from gentle to moderately steep and where stream valleys are sufficiently depressed to permit the storage of water to a considerable depth.

An excavated pond is a body of water created by excavating a pit or dugout. These usually are constructed in relatively level areas. The fact that their capacity is obtained almost entirely by excavation limits their use to locations where only a small supply of water is required.

Ponds are also built in gentle to moderately sloping areas where capacity is obtained by both excavation and the construction of a dam. For the purpose of classification, these are considered to be embankment-type ponds if the depth of water impounded against the embankment exceeds three feet.

4. SELECTING THE POND SITE

The selection of a suitable pond site should begin with preliminary studies of possible sites. Where more than one site is available, each should be studied separately with a view of selecting the one that proves most practical and economical.

From an economic viewpoint, a pond should be located where the largest storage volume can be obtained with the least amount of earthfill. This condition generally will occur at a site where the valley is narrow, side slopes are relatively steep, and the slope of the valley floor will permit a large deep basin. Such sites tend to minimize the area of shallow water; however, they should be examined carefully for adverse geologic conditions. Except where the pond is to be used for wildlife, large areas of shallow water should be avoided due to excessive evaporation losses and the growth of noxious aquatic plants.

Ponds to be used for watering livestock should be spaced so that livestock will not have to travel more than one-quarter mile to reach them in rough, broken country, nor more than one mile in smooth, relatively level areas. Forcing livestock to travel long distances for water is detrimental to both the livestock and the grazing area. Overgrazing near water and unused feed far from water are characteristic of inadequate water distribution.

Where water must be conveyed for use elsewhere, such as for irrigation or fire protection, ponds should be located as close to the point of use as is practical.

Ponds to be used for fishing, boating, swimming and other forms of recreation should be readily accessible by automobile. This is particularly true where the general public is charged a fee for use of the pond. The success of such an income-producing enterprise may well depend on the accessibility of the pond.

Pollution of farm pond water should be avoided by selecting a site where drainage from farmsteads, feeding lots, corrals, sewage lines, mine dumps and similar areas will not reach the ponds. Where this cannot be done practically, the drainage from such areas should be diverted from the pond.

The pond should not be located where sudden release of the water, due to failure of the dam, would result in loss of life, injury to persons or livestock, damage to residences or industrial buildings, railroads or highways, or cause interruption of use or service of public utilities. Where the only suitable site presents one or more of these hazards, a more detailed investigation should be made.

Low-hanging powerlines present a hazard to fishermen and others using farm ponds. They may be within reach of a fishing rod held by someone fishing from the top of the dam. Sites under such lines should be avoided.

A check should be made to insure that no buried pipelines or cables exist in the construction area. These might be broken or punctured by the excavating equipment, resulting not only in damage to the utility but in injury to the operator of the equipment as well. Where such a site must be used, the utility owners should be contacted prior to foundation investigation or construction.

5. PRELIMINARY SITE STUDIES

In addition to the considerations mentioned for the selection of a pond location, there are other physical characteristics of the drainage area and the pond site which should be investigated before the final selection is made.

ADEQUACY OF THE DRAINAGE AREA

Where surface runoff is the main source of water supply, the contributing drainage area should be large enough to yield sufficient runoff to maintain the water supply in the pond during all periods of intended use. The drainage area should not be so large, however, as to require large and expensive overflow structures to bypass runoff safely.

The amount of runoff that can be expected annually from a watershed of a given area depends on so many factors that no set rule can be given for its determination. The physical characteristics of the watershed that have a direct effect on the yield of water are land slopes, soil infiltration, vegetal cover and surface storage. Storm characteristics such as the amount, intensity and duration of rainfall also affect water yield. All of these characteristics vary widely throughout the United States.

Exhibit 11-1 can be used as a general guide for estimating the size of a watershed required for each acre-foot of capacity in a pond or reservoir to maintain normal pool level, if more precise local data is not available. The map does not apply when ponds are used for irrigation.

MINIMUM POND DEPTH

For a permanent water supply, it is necessary to provide sufficient water depth to meet the intended use and to offset seepage and evaporation losses. These losses vary in different sections of the country and also from year to year in any section. Table 11-3 shows recommended minimum depths of water for farm ponds, assuming normal seepage and evaporation losses. Greater depths are desirable where a year-round water supply is essential or where seepage losses may exceed three inches per month. See State Standards and Specifications for local minimum depths.

Table 11-3. Recommended minimum depths of ponds and reservoirs

Climate	Annual Rainfall (inches)	Minimum Water Depth Over 25 percent of the Area (feet)
Superhumid	Over 60	6
Humid	40 - 60	8
Subhumid - Moist	30 - 40	9
Subhumid - Dry	20 - 30	10
Semiarid	10 - 20	12
Arid	Under 10	14

DRAINAGE AREA PROTECTION

To maintain the required depth and capacity of a farm pond, it is necessary that the inflow be reasonably free from sediment. The best protection is adequate erosion control on the contributing drainage area. Land under a cover of permanent vegetation, such as trees or grasses, makes the most desirable drainage area. If such an area is not available, cultivated areas that are protected by necessary conservation practices, such as terracing, contour tillage, strip-cropping, conservation cropping systems, vegetated desilting areas, and other soil-improvement practices, may be utilized as a last resort. Allowance should be made for the expected sedimentation during the effective life of the structure.

ADEQUACY OF POND CAPACITY

To insure that the water stored in a farm pond will be adequate to satisfy the intended uses, a reasonable estimate of the pond capacity should be made. The following is a simple method of estimating capacity.

The pond-full water elevation is established and the waterline is staked at this elevation. The widths of the valley at this elevation are measured at regular intervals and these measurements are used to compute the pond-full surface area in acres. The surface area is multiplied by 0.40 times the maximum water depth at the dam. For example, a pond with a surface area of 3.2 acres and a depth of 12.5 feet at the dam would have an approximate capacity of 0.4 x 12.5 x 3.2 = 16.0 ac.ft. (1 acre-foot = 325,857 gallons). If a more accurate answer is required, the surface area at successive intervals of elevation may be determined and the average end-area method may be used to compute the volume.

6. ENGINEERING SURVEYS

Once the location of the pond or reservoir has been determined, sufficient engineering surveys should be made so that the dam, spillway and other features of the pond can be planned.

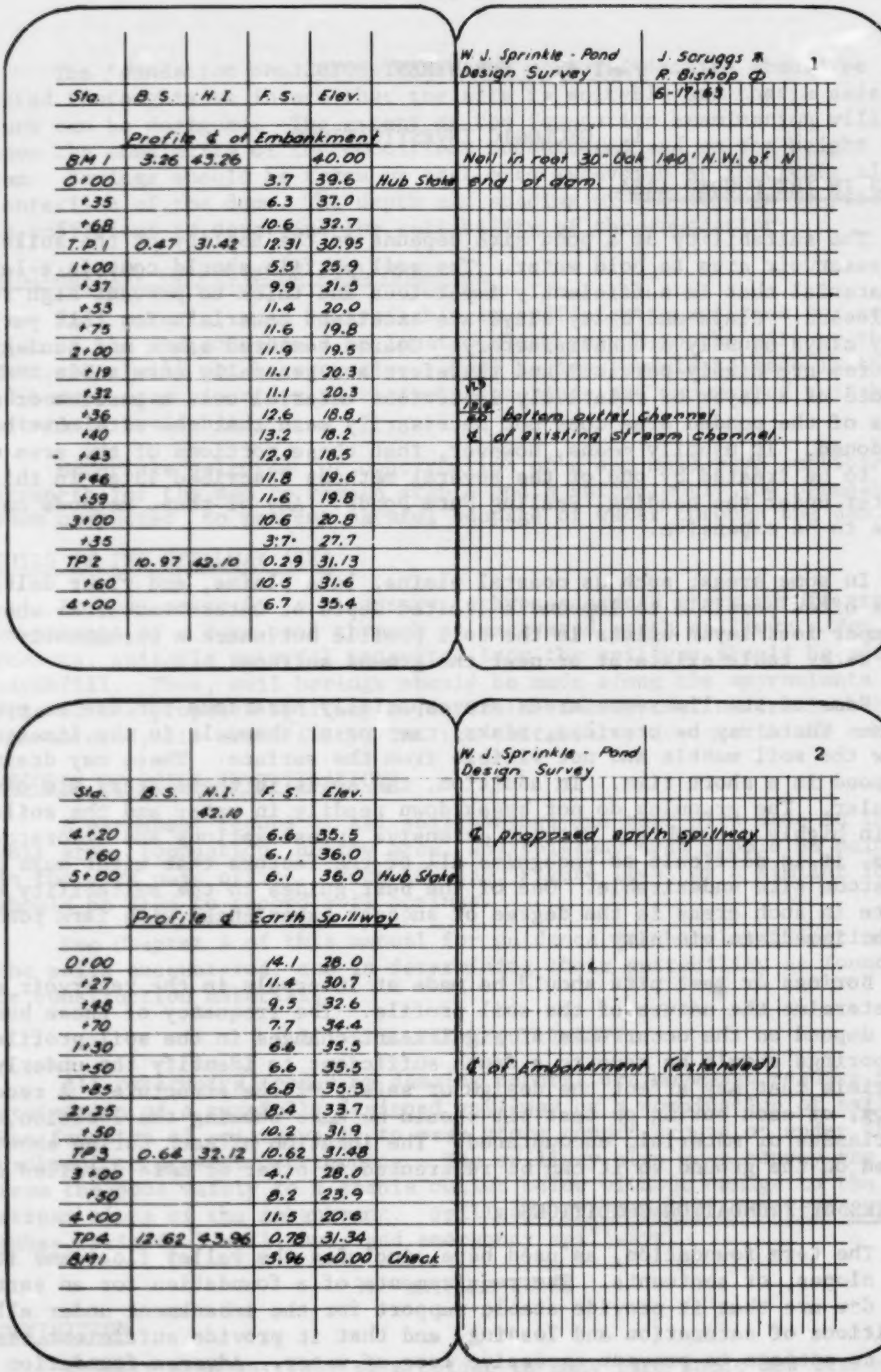
Surveys for embankment-type ponds normally will consist of a profile of the centerline of the dam, a profile of the centerline of the earth spillway, and sufficient measurements for estimating the pond capacity. For the larger and more complex reservoirs, particularly those used to store water for irrigation, a complete topographic survey of the entire pond site and cross-section surveys of embankment and spillway locations may be required.

The profile along the centerline of the proposed dam should extend up both sides of the valley above the expected elevation of the top of the dam and beyond the probable location of the earth spillway. The profile should show ground surface elevations at all significant changes in the ground slope and at intervals no greater than 50 feet. The profile assists in establishing critical elevations for the structure including normal pool, crest of the emergency spillway and top of the embankment. It is used also to compute the volume of earth required to construct the dam.

A similar profile should be run along the centerline of the earth spillway from a point on the upstream end, well below the selected normal water surface elevation, to a point on the downstream end where water can be safely discharged without damage to the structure. This profile serves as a basis for determining the slope and dimensions of the spillway.

All surveys made at the pond site should be tied to reference points and a bench mark. These may be a large spike driven into a tree, an iron rod driven flush with the ground, a point on the concrete headwall of a culvert, or any other object so located that it can be expected to remain undisturbed until construction of the dam has been completed. Figure 11-3 shows a sample set of notes for a farm pond design survey.

Engineering surveys for excavated ponds are relatively simple where no water is stored against an embankment. Usually the four corners of the proposed excavation are located on the ground and rod readings taken at these points. These readings should be referenced to a bench mark and recorded. Engineering surveys for both embankment and excavated ponds may be recorded on approved standard forms or data sheets.



W. J. Sprinkle - Pond Design Survey

J. Scruggs ®
R. Bishop ⏀
6-17-63

1

Sta.	B. S.	H. I.	F. S.	Elev.		
	Profile ℄ of Embankment					
BM 1	3.26	43.26		40.00		Nail in root 30" Oak 140' N.W. of N
0+00			3.7	39.6	Hub Stake	end of dam.
+35			6.3	37.0		
+68			10.6	32.7		
T.P. 1	0.47	31.42	12.31	30.95		
1+00			5.5	25.9		
+37			9.9	21.5		
+53			11.4	20.0		
+75			11.6	19.8		
2+00			11.9	19.5		
+19			11.1	20.3		
+32			11.1	20.3		
+36			12.6	18.8		℄ bottom outlet channel
+40			13.2	18.2		℄ of existing stream channel.
+43			12.9	18.5		
+46			11.8	19.6		
+59			11.6	19.8		
3+00			10.6	20.8		
+35			3.7	27.7		
TP 2	10.97	42.10	0.29	31.13		
+60			10.5	31.6		
4+00			6.7	35.4		

W. J. Sprinkle - Pond Design Survey

2

Sta.	B. S.	H. I.	F. S.	Elev.		
		42.10				
4+20			6.6	35.5		℄ proposed earth spillway
+60			6.1	36.0		
5+00			6.1	36.0	Hub Stake	
	Profile ℄ Earth Spillway					
0+00			14.1	28.0		
+27			11.4	30.7		
+48			9.5	32.6		
+70			7.7	34.4		
1+30			6.6	35.5		
+50			6.6	35.5		℄ of Embankment (extended)
+85			6.8	35.3		
2+35			8.4	33.7		
+50			10.2	31.9		
TP 3	0.64	32.12	10.62	31.48		
3+00			4.1	28.0		
+50			8.2	23.9		
4+00			11.5	20.6		
TP 4	12.62	43.96	0.78	31.34		
BM 1			3.96	40.00	Check	

Figure 11–3 Sample notes for a pond design survey.

PART II - EMBANKMENT PONDS

1. GEOLOGIC INVESTIGATIONS

SOILS IN THE PONDED AREA

The suitability of a pond site depends on the ability of the soils in the reservoir area to hold water. The soil profile should contain a layer of material that is sufficiently impervious and thick to prevent high seepage losses. Clays and silty clays are excellent materials for this purpose. Sandy clays usually are satisfactory. Coarse textured sands and sand-gravel mixtures are highly pervious and therefore are generally unsuitable. The absence of a layer of relatively impervious material over a portion or portions of the ponded area does not necessarily mean that the site must be abandoned. It usually means, however, that these portions of the area will have to be treated by one of the several methods described later in this chapter under the heading, Sealing Farm Ponds. Any of these methods may prove to be expensive.

In some areas, such as coastal plains, lake plains, and river deltas, it is often possible to impound a limited depth of water over areas where no impervious layer exists in the soil profile but where a permanently high water table exists at or near the ground surface.

Some of the limestone areas are especially hazardous for use as pond sites. There may be crevices, sinks, caverns or channels in the limestone below the soil mantle and not visible from the surface. These may drain the pond in a short time. In addition, the soils in these areas are often granular. The granules do not break down readily in water and the soils remain highly permeable. Without extensive investigations and laboratory tests, it is difficult to recognize all of the factors that might make a limestone site undesirable. One of the best guides to the suitability of a site in such areas is the degree of success experienced with farm ponds in the immediate vicinity.

Borings or test pits should be made at intervals in the reservoir area to determine the nature of the soil profile. The frequency of these borings will depend on the occurrence of significant changes in the soil profile. The borings should be made to a depth sufficient to identify the underlying materials that may affect the design or safety of the structure. A record, or log, of each boring or test pit should be made showing the location, depth and classes of materials encountered. The location of each boring should be marked on the ground so it can be referenced to other or more detailed surveys.

STUDIES OF FOUNDATION CONDITIONS

The term foundation, as used here, includes the valley floor and its side slopes, or abutments. The requirements of a foundation for an earthfill dam are that it provide stable support for the embankment under all conditions of saturation and loading, and that it provide sufficient resistance to seepage to prevent excessive loss of water. Adverse foundation conditions can lead to failure of a dam due to cracking, piping, sliding, settlement, or uplift.

The foundation conditions under the proposed damsite should be investigated thoroughly to insure that the site is suitable and that a safe structure can be designed. The extent of the foundation examination will depend upon the complexity of the conditions encountered and on the height of the dam. Borings should be taken or test pits excavated at intervals along the centerline of the dam. The depth and spacing of the borings or pits should be sufficient to determine the suitability of the foundation.

AVAILABILITY OF SUITABLE FILL MATERIAL

Fill material must be available in sufficient quantities for construction of the dam and should be located close enough to the site so that placement costs will not be excessive. Soil borings should be made in the selected borrow areas in order to estimate the kinds and amounts of suitable fill materials available.

Materials selected for construction of a dam must have sufficient strength for the dam to remain stable and a sufficiently low permeability, when compacted, to prevent harmful seepage of water through the dam.

SOILS IN THE SPILLWAY AREA

In most cases it is necessary to bypass excess storm runoff around the embankment of a farm pond through an excavated earth spillway. For economic reasons, suitable material excavated from the spillway should be used in the earthfill. Thus, soil borings should be made along the approximate centerline of the proposed spillway to determine the type of material that will be encountered, its erodibility, and its suitability for use in the embankment.

RECORDS OF SOILS INVESTIGATIONS

A permanent record of all soil borings and test pits made in the reservoir area, foundation, borrow area, and spillway area should be maintained in the work unit office. Form SCS 538, Figure 11-4, or a similar form, should be used to record soil borings.

See Chapter 4 of this manual for guidance in the classification of the soils encountered, and in determining their suitability as foundation or construction materials.

2. SPILLWAY REQUIREMENTS

All reservoirs formed by damming natural drainageways require the protection of a carefully designed spillway or a combination of spillways. The function of spillways is to pass storm runoff around or under the embankment to prevent overtopping. The spillway also must convey the water from the pond safely to a stable outlet below without damage to the downstream slope of the embankment. Spillways are usually classified as trickle tubes, principal spillways, and emergency spillways.

3. TRICKLE TUBES

DEFINITION

A small pipe spillway is provided in many farm ponds and reservoirs to protect the vegetative cover in the emergency spillway from prolonged saturation by continuous flow, spring flow, or low flows that may continue for several days during snowmelt or following a storm. This type of spillway is designed to discharge such a small percentage of the peak flow that

Form SCS 538

SOIL INVESTIGATION TO DETERMINE SUITABILITY OF PROPOSED POND SITE

FARMER'S NAME John M. Doe DISTRICT Greenville
DATE March 1, 1962 COUNTY Greenville
S. C. S. PHOTO SHEET NO. AX-16B-422 WORK UNIT Greenville

WATERSHED AREA MEASUREMENTS

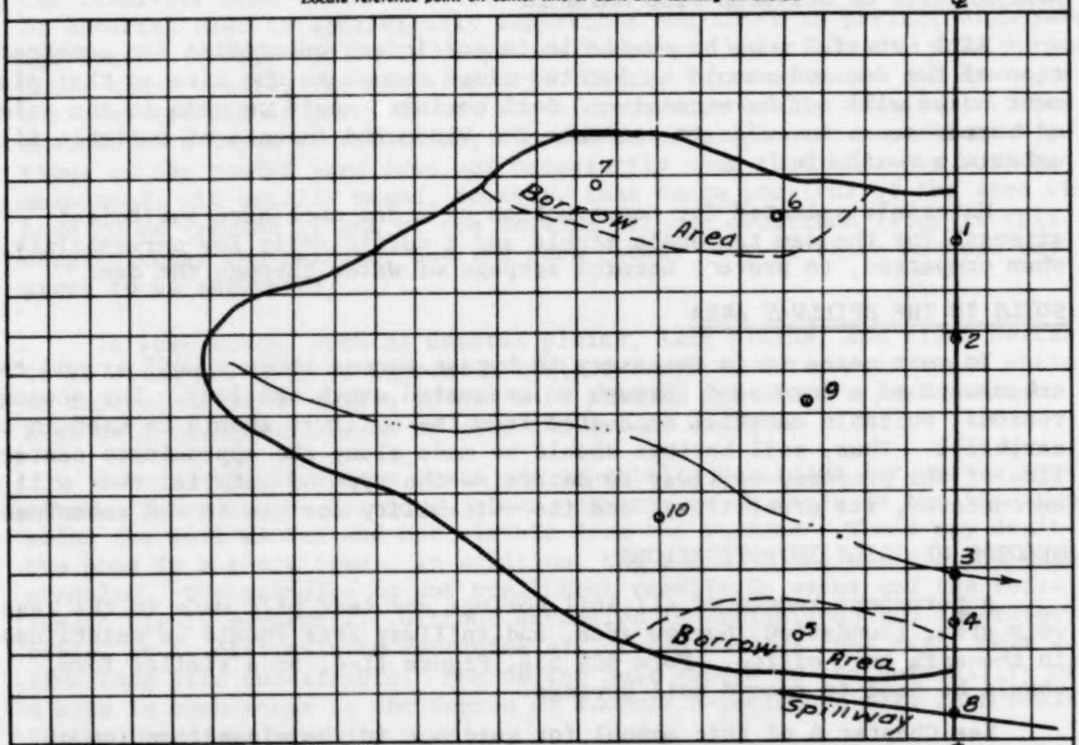
CROPLAND 10 ACRES PASTURE 14 ACRES
WOODLAND 11 ACRES TOTAL 35 ACRES

POND CLASS

H. Smith
WORK UNIT CONSERVATIONIST

SKETCH OF PROPOSED POND SHOWING WHERE BORINGS WERE MADE (Approx. scale 1" = ______ feet)

Locate reference point on center line of dam and identify on sketch.



BORING NUMBER AND PROFILE

Make and list dam-site and spillway borings first - then ponded area and borrow pit borings - separate with vertical red line.
(Continued on back where necessary) Show water table elevations on dam-site borings.

SHOW DEPTH SCALE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1.0	SM	SM	ML	SM	SC	SM	SM	SC	ML	ML													
2.0	CL	SM	ML	CL	SC	CL	SM	SC	SM	ML													
3.0	CL	SM	SM	CL	SC	CL	SM	SC	SM	ML													
3.5	CH	CL	SM	CL	SM	CL	CL	SM	SM	SM													
4.0	CH	CL	CL	CH	SM	CL	CL	SM	SM	SM													
5.0	CH	CL	CL	CH	CL	CH	CL	CL	CH	CL													
6.0	CH	CH	CH	CH	CH	CH	CH	CL	CH	CL													

BORINGS MADE BY P. D. Waters SIGNATURE & TITLE P.D. Waters Area Engr.

Figure 11-4 Soil investigation form. (Sheet 1 of 2)

TYPES OF MATERIAL ENCOUNTERED IN BORINGS

GW	Well graded gravels; gravel-sand mixtures
GP	Poorly graded gravels
GM	Silty gravels; gravel-sand-silt mixtures
GC	Clayey gravels; gravel-sand-clay mixtures
SW	Well graded sands; sand-gravel mixtures
SP	Poorly graded sands
SM	Silty sand
SC	Clayey sands; sand-clay mixtures
ML	Silts; silty, v. fine sands; sandy or clayey silts
CL	Clays of low to medium plasticity; silty, sandy or gravelly clays
CH	Inorganic clays of high plasticity; fat clays
MH	Elastic silts; micaceous or diatomaceous silts
OL	Organic silts and organic silty clays of low plasticity
OH	Organic clays of medium to high plasticity

1. Suitable material for embankment is available ☒ **Yes** ☐ **No** *(Indicate where located on the sketch on reverse side)*

REMARKS:

Material in borrow areas and spillway area is suitable for embankment fill.

2. Explain hazards requiring special attention in design *(Seepage, spring, rock etc.)*

Clean out old channel to good material. This should extend for its entire length under the embankment. Backfill with material from borrow area, and compact as required for maximum density.

GENERAL REMARKS:

Site is satisfactory for stock water pond.

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51

Figure 11–4 **Soil investigation form.** **Sheet 2 of 2**

it has no measurable effect on the emergency spillway design. This type of spillway is commonly called a trickle tube.

DESIGN CAPACITY

The design capacity of a trickle tube should be adequate to discharge long-duration, continuous, or frequent flows without flow through the earth spillway.

4. PRINCIPAL SPILLWAYS

DEFINITION

The principal spillway is constructed of permanent material, and usually is designed to provide flood protection or to reduce the frequency of operation of the emergency spillway. Its discharge capacity depends upon the purpose of the reservoir and the use for which the spillway is designed. If the reservoir is to be used for retarding flood flow, it discharges a low percentage of the peak flow. At locations where an emergency spillway is not feasible the principal spillway should be designed to discharge the runoff for the design storm.

DROP INLET SPILLWAYS

One type of principal spillway that is commonly used with farm ponds and reservoirs is the drop inlet spillway. It consists of a pipe barrel located under the embankment with a riser connected to the upstream end. The elevation of the crest of the riser determines the normal pool level in the reservoir. This type of spillway may be used to drain the pond or to supply water for irrigation or other purposes by installing a valve or gate in the upstream end of the barrel.

Design

Small diameter pipes are particularly susceptible to clogging with trash and rodents. For this reason no barrel smaller than 6 inches in diameter and no riser smaller than 8 inches in diameter should be used. Where the riser is to be constructed of reinforced concrete or concrete block, the inside dimensions should not be smaller than 24 by 24 inches.

The crest elevation of the emergency spillway should be located at an elevation above the crest of the drop inlet equal to the head required to develop design flow through the principal spillway conduit.

Drawings and design information are given in Chapter 6 of this manual. Construction methods and materials are covered in Chapter 17. Also see Exhibit 11-4 for determining the capacity of principal spillways considering temporary storage.

HOOD INLET SPILLWAYS

Another type of principal spillway commonly used with farm ponds and reservoirs is the hood inlet spillway. It consists of a pipe laid in the earth embankment in a manner that the elevation of the invert of the pipe at its upstream end establishes the normal pool level in the reservoir. The inlet end of the pipe is cut at an angle to form the hood. An anti-vortex device, usually made of metal, is attached to the entrance of the pipe to increase the hydraulic efficiency of the tube. The hood inlet spillway often can be constructed at less cost than the drop inlet type because there is no expense for a riser. This type of spillway has one major disadvantage in that it cannot be used as a drain or water supply pipe.

Pipe smaller than 6 inches in diameter should not be used because of the danger of becoming clogged. The crest elevation of the emergency spillway should be located a distance above the invert or crest elevation of the hood inlet spillway at least equal to the value of the minimum head, h, required to provide full pipe flow, but in no case less than 12 inches.

See Chapter 6 of this manual for further design information and typical installations, and Chapter 17 for construction methods and materials. See Exhibit 11-4 for determining the capacity of principal spillways considering temporary storage.

5. EMERGENCY EARTH SPILLWAYS

An emergency earth spillway is an earth or a vegetated earth channel, usually designed to discharge flow in excess of the principal spillway design discharge. Where watersheds are small and long duration flows are not a problem, it may be feasible to handle the runoff safely with only a vegetated spillway.

Earth spillways, as discussed here, apply to both the vegetated and nonvegetated spillways, the latter being used where climatic or soil conditions make it impossible to grow or maintain a suitable grass cover. Earth spillways are usually excavated, but may exist as a natural spillway such as well-vegetated natural draw, saddle or drainageway. In either case the spillway must discharge the design peak flow at a non-erosive velocity to a safe point of release. Ordinarily, earth spillways whether vegetated or nonvegetated should not be built on fill material.

LIMITATIONS

Earth spillways have certain limitations. They should be used only where the soils and topography will permit safe discharge of the peak flow at a point well away from the dam and at a velocity which will not cause appreciable erosion. Temporary flood storage provided in the reservoir may be used to reduce the design flow or frequency of use of the spillway.

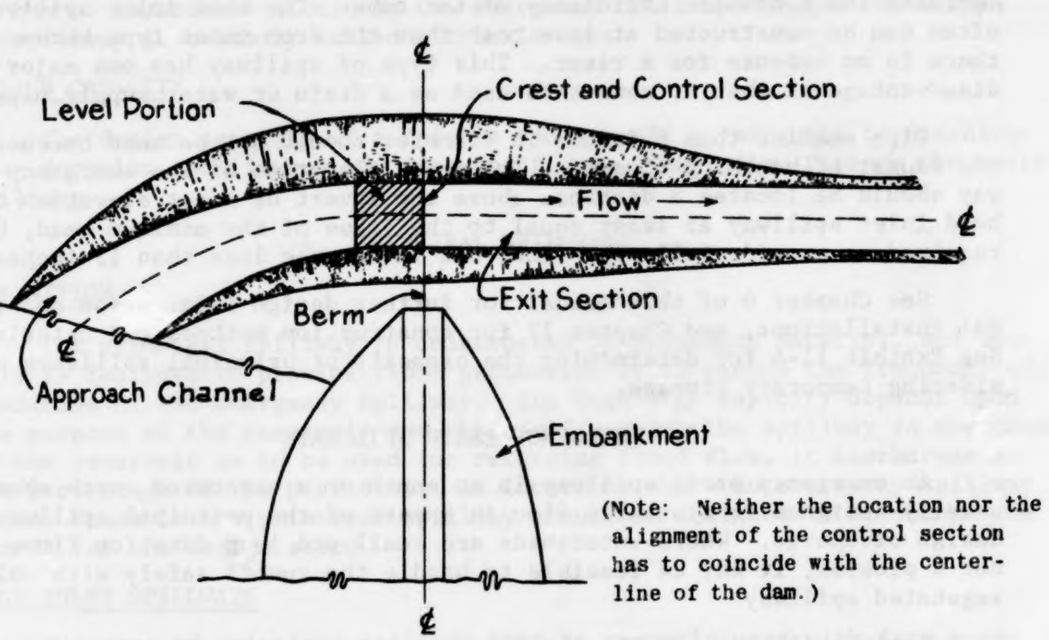
DESIGN SPILLWAY CAPACITY

Emergency earth spillways should have the capacity to discharge the peak flow from the watershed resulting from a storm expected to occur once in 25 years or the storm required by State Standards and Specifications. The procedure for determining peak flood flow is presented in Chapter 2 of this manual. Where the flow in the principal spillway is appreciable, the design capacity of the emergency spillway may be reduced by that amount.

EXCAVATED EARTH SPILLWAYS

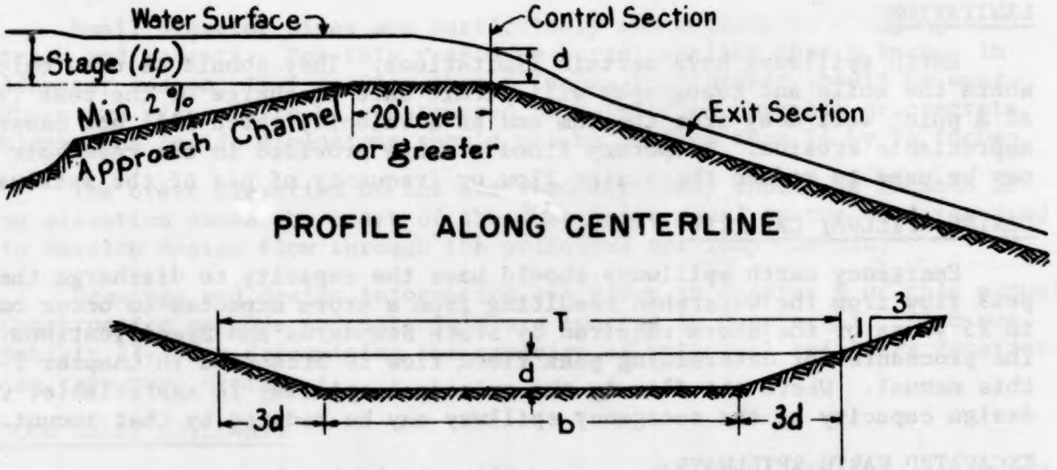
Elements of Excavated Spillways

Excavated earth spillways consist of the three elements shown in Figure 11-5. These are the approach channel, control section and exit

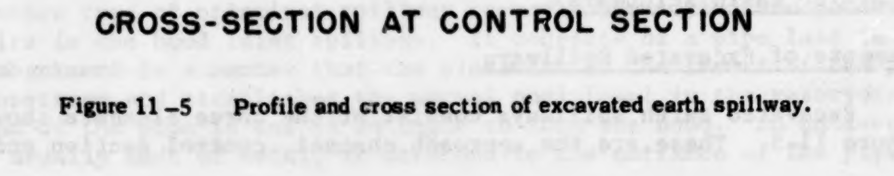

Level Portion
Crest and Control Section
Flow
℄
Exit Section
Berm
℄
Approach Channel
Embankment
℄

(Note: Neither the location nor the alignment of the control section has to coincide with the centerline of the dam.)

PLAN VIEW OF EXCAVATED EARTH SPILLWAY


Water Surface
Control Section
Stage (H_p)
d
Min. 2%
Approach Channel
20' Level or greater
Exit Section

PROFILE ALONG CENTERLINE



CROSS-SECTION AT CONTROL SECTION

Figure 11–5 Profile and cross section of excavated earth spillway.

channel. Each element has a special function. The flow enters the spillway through the approach channel. The flow is controlled in the level portion and passes through critical depth at the control section, which is the downstream edge of the level portion. The flow is then discharged through the exit section. Designed flow condition will occur only where the exit section slope is equal to or greater than the critical slope.

Excavation of the approach section or the exit section, or both, may be omitted where the natural slopes meet the minimum slope requirements of Exhibits 11-2 or 11-3. The direction of slope of the exit section must be such that outflow will not flow against any part of the dam. Wing dikes, sometimes called kicker levees or training levees, may be used to direct the outflow to a safe point of release.

The spillway should be excavated into original earth for the full design depth. Where this is not practical, the end of the dam and any earthfill constructed to confine the flow should be protected by vegetation or riprap. It is desirable that the entrance to the approach channel be widened so it is at least 50 percent greater than the designed bottom width at the control section. The approach channel should be reasonably short and should be planned with smooth, easy curves for alignment. It should have a slope toward the reservoir of not less than 2.0 percent, except in rock, to insure drainage and low inlet losses.

The control section should be located near the intersection of the extended centerline of the dam with the centerline of the spillway. A level section, at least 20 feet in length, should be provided just upstream from the control section.

The exit section must have a slope that is adequate to discharge the peak flow within the channel. The slope, however, must be no greater than that which will result in maximum permissible velocities for the soil type or the planned grass cover. (See Exhibits 11-2 and 11-3 for minimum and maximum slopes.) Permissible velocities usually do not exceed 5.5 feet per second and seldom should exceed 6.0 feet per second. The exit channel should be straight and should confine the outflow to a point where the water may be released without damage to the fill.

Selecting Spillway Dimensions

With the required discharge capacity, Q, known and the natural slope of the exit channel determined from a plotting of the spillway centerline profile, the bottom width of the control and exit sections and the depth of flow (stage) may be selected from Exhibits 11-2 or 11-3. The natural slope of the exit channel should be altered as little as possible. Exhibit 11-2 should be used where the spillway is to be excavated in cohesive soils with a high clay content. Exhibit 11-3 should be used where highly erodible soil exists.

Spillway side slopes should be no steeper than 3:1 unless the spillway is excavated into rock, in which case the side slopes may be vertical.

Usually the selected bottom width of the channel should not exceed 35 times the design depth of flow. Where this ratio of bottom width to depth is exceeded, the channel is likely to be damaged by meandering flow and accumulated debris. Whenever the required bottom width of the spillway is excessive, consideration should be given to the use of a spillway at each end of the dam. These two spillways need not be of equal width so long as their total capacity meets requirements. In cases where the required discharge capacity exceeds the ranges shown in the above exhibits, or topographic conditions will not permit the construction of the exit channel bottom with a slope that falls within the ranges shown in these exhibits, the need for a mechanical spillway is indicated.

See Exhibit 11-4 for principal spillway discharge requirements adjusted for temporary storage provided in the reservoir. Emergency spillway design flow may be adjusted to consider the outflow through the principal spillway.

NATURAL SPILLWAYS

Many times large expanses of good sod are destroyed to provide the minimum slopes for an excavated spillway. This may increase the construction cost and will increase maintenance costs. Wherever there is a good vegetative cover in the spillway area and the topography - such as a natural saddle - is suitable, first consideration should be given to the use of a natural spillway. The discharge capacity can be computed by Manning's formula (see Chapter 3 of this manual) or by the following procedures.

Discharge through Natural Vegetated Spillways

In a natural spillway the outflow takes place around the end of the embankment on natural or undisturbed ground. The number of possible cross sections and profile shapes is so great that an analysis here of the rate of flow for each condition is impractical.

In most cases the control section will be V-shaped, one side determined by the embankment end and the other by the natural ground. The ground slope should be determined along a line perpendicular to the contour direction within the flow depth range. See Figure 11-6.

The end of dam should be approximately perpendicular to the contours of the abutment. A short wing levee may be used to protect the toe of the embankment. The slope away from the control section must be equal to or greater than the critical slope, s_c, unless the water can spread over an area at a depth equal to or less than the critical depth, d_c. Where a diversion or waterway exit channel needs to be connected to the control section, Exhibit 11-5 must not be used unless the critical slope criteria can be satisfied. To do otherwise would result in an unsafe design. It may be assumed that conditions for critical flow exist if the slope below the control section exceeds 1.8 percent.

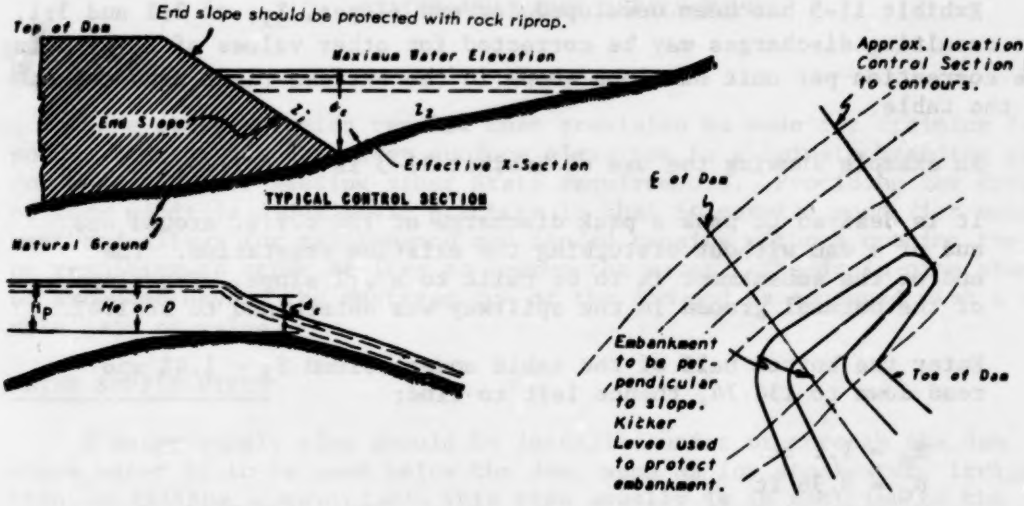

Top of Dam
End slope should be protected with rock riprap.
Maximum Water Elevation
Z1
dc
Z2
End Slope
Effective X-Section
TYPICAL CONTROL SECTION
Natural Ground
Hp
He or D
dc
Approx. location of Control Section 90° to contours.
℄ of Dam
Embankment to be perpendicular to slope. Kicker Levee used to protect embankment.
Toe of Dam

Figure 11–6 Profile and cross section of a natural vegetated spillway.

Discharge of natural spillways is computed by the equation,

$$Q(\text{cfs}) = A\,V$$

$$Q(\text{cfs}) = \sqrt{g/2}\left(\frac{Z_1 + Z_2}{2}\right)\left(4/5\ H_e\right)^{5/2}$$

$$A = \left(\frac{Z_1 + Z_2}{2}\right)\left(4/5\ H_e\right)^2 \text{ in sq. ft.}$$

Z_1 = Embankment slope at spillway end, as in the ratio 2:1

Z_2 = Slope of natural ground at right angle to the flow in the spillway, expressed as a ratio.

V_c = Critical velocity, fps = $\sqrt{\frac{g d_c}{2}}$

d_c = Critical depth, feet = $4/5\ H_e$

H_e = Energy gradient. Approx. equal to depth of water in reservoir above spillway crest.

H_p = Depth of pool surface above crest of emergency spillway. For small ponds this is approximately equal to H_e in natural spillways.

g = Acceleration of gravity = 32.2

Determining Maximum Water Elevation in Reservoir

With the required discharge capacity, Q, and the end slope of the embankment, Z_1, both known and the slope of the natural ground, Z_2, taken from a profile plotting, the maximum depth of water in the spillway above the crest, H_e, can be obtained from Exhibit 11-5. This depth is added to the elevation of the spillway crest to determine the maximum elevation to which water will rise in the reservoir.

Exhibit 11-5 has been developed for end slopes, Z_1, of 2:1 and 3:1. The resulting discharges may be corrected for other values of Z_1 by using the correction per unit of slope shown in the extreme right hand column of the table.

An example showing the use of Exhibit 11-5 is as follows:

> It is desired to pass a peak discharge of 134 c.f.s. around one end of a dam without disturbing the existing vegetation. The end of the embankment is to be built to a 3:1 slope. The slope of the natural ground in the spillway was determined to be 1.4%.
>
> Enter the bottom half of the table under column Z_2 = 1.4% and read down to 134.74, thence left to find:
>
> H_e = 1.2 ft.
> d_c = 0.96 ft.
> V_c = 3.928 ft./sec.
>
> Although the value, H_e = 1.2 ft. is depth of flow plus velocity head, it will approach the total depth "D" at a point about 50 feet upstream from the spillway and may be safely used as the maximum depth of flow through the spillway. This depth plus freeboard, which is discussed later, will be the effective height of embankment above the spillway crest.
>
> The embankment end slope may be other than 2:1 or 3:1. For each unit that Z_1 is increased, the discharge value in Exhibit 11-5 should be increased by the correction factor shown in the right hand column on the same horizontal line. Likewise, the discharge value would be reduced by the correction factor for each unit that Z_1 is decreased.
>
> From the above example, if H_e = 1.2 and Z_1 = 4:1 instead of 3:1, the discharge rate of the spillway would be 134.74 plus a correction of 1.81, or 136.55 c.f.s.

PROTECTION AGAINST EROSION

Earth spillways should be protected against erosion by a good vegetal cover, if soil and climate permit. As soon after construction as is practical, the entire spillway area should be thoroughly prepared for seeding or sodding. Liberal amounts of fertilizer should be used where moisture is available or can be applied. In cases where the subsoil is low in fertility, it may be desirable to save the topsoil and spread it in the excavated spillway. Adapted perennial grasses or perennial grasses and legumes should be sown, protected, and treated until a good stand has been established. Mulching is usually necessary to protect the seeding on the spillway slopes. Irrigation of the spillway area is often needed to assure adequate germination and growth, particularly when seeding must be done during relatively dry periods. Where the added cost is justified, sprigging or sodding with suitable grasses will afford quick protection.

6. DRAINS AND WATER SUPPLY PIPES

DRAIN PIPES

Some state agencies require that provision be made for draining farm ponds, fluctuating the water surface elevation to eliminate breeding places for mosquitos, or meeting other State requirements. Providing for drainage of farm ponds is a desirable practice in that it permits good fish management and allows for maintenance and needed repairs without cutting the fill or resorting to other devices to remove the water. The drain pipe should be extended beyond the upstream toe of the dam and be equipped with a suitable gate or valve.

WATER SUPPLY PIPES

A water supply pipe should be installed under or through the dam where water is to be used below the dam, such as for stockwater, irrigation, or filling a spray tank. This pipe usually is in addition to the principal spillway or trickle tube. The water supply pipe should have water-tight joints and be equipped with a suitable valve and strainer at its upper end. For small rates of flow, such as are needed to fill livestock or spray tanks, 1½-inch diameter steel pipe is generally used. Where larger rates of flow are required, such as for irrigation purposes, larger diameter pipe are commonly used. Water supply pipes should be provided with anti-seep collars to retard seepage. (See Figure 11-7 for a sketch of a stock watering facility.)

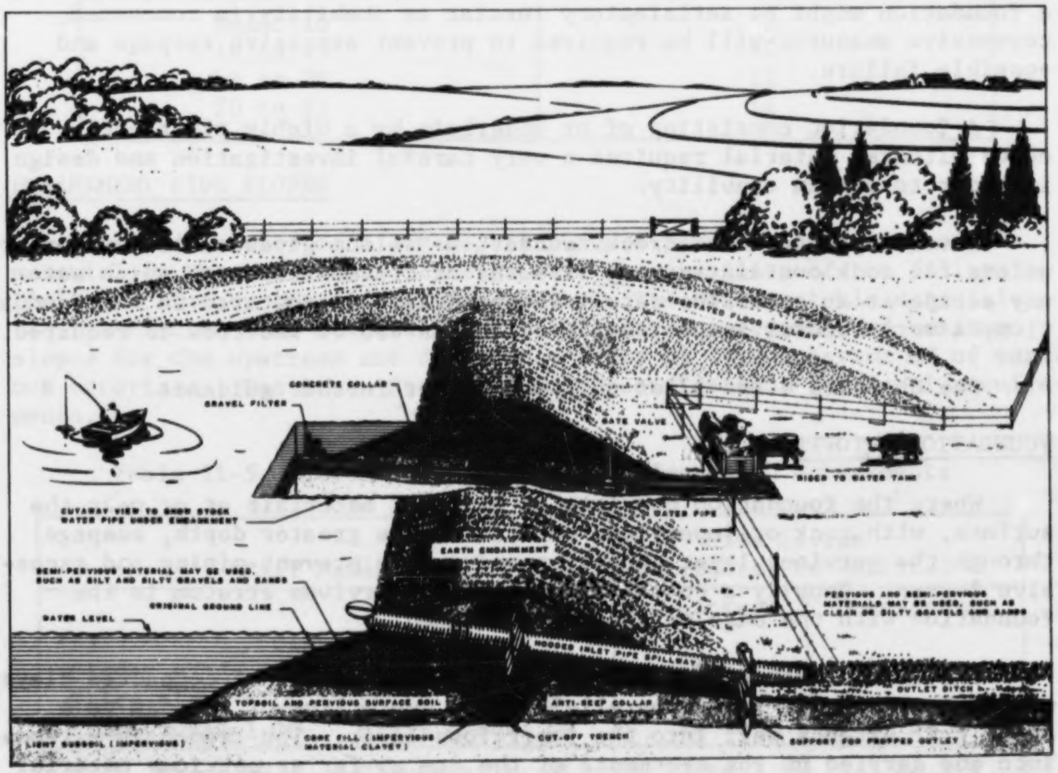

VEGETATED FLOOD SPILLWAY
CONCRETE COLLAR
GRAVEL FILTER
GATE VALVE
RISER TO WATER TANK
CUTAWAY VIEW TO SHOW STOCK WATER PIPE UNDER EMBANKMENT
WATER PIPE
EARTH EMBANKMENT
SEMI-PERVIOUS MATERIAL MAY BE USED, SUCH AS SILT AND SILTY GRAVELS AND SANDS
PERVIOUS AND SEMI-PERVIOUS MATERIALS MAY BE USED, SUCH AS CLEAN OR SILTY GRAVELS AND SANDS
ORIGINAL GROUND LINE
WATER LEVEL
HOODED INLET PIPE SPILLWAY
OUTLET DITCH
TOPSOIL AND PERVIOUS SURFACE SOIL
ANTI-SEEP COLLAR
LIGHT SUBSOIL (IMPERVIOUS)
CORE FILL (IMPERVIOUS MATERIAL CLAYEY)
CUT-OFF TRENCH
SUPPORT FOR PROPPED OUTLET

Figure 11-7 Embankment pond equipped with a stock watering facility

7. DESIGN OF EARTHFILL EMBANKMENTS

FOUNDATIONS

It is possible to construct a safe earthfill dam on almost any foundation if the foundation has been thoroughly investigated and the design and construction procedures are adapted to site conditions. Some foundation conditions require construction measures that are relatively expensive which, in the case of small farm ponds, cannot be justified. Sites with such foundation conditions ordinarily should be abandoned.

The most satisfactory foundation is one that consists of, or is underlain at a shallow depth by a thick layer of relatively impervious consolidated material. Such foundations cause no stability problems. Where a suitable layer occurs at the surface, no special measures are required. It is sufficient to remove the top-soil and scarify or disk the area to provide a bond with the material in the dam.

Where the impervious layer is overlain by previous material a compacted clay cutoff, extending from the surface of the ground into the impervious layer, is required to prevent possible failure by piping and to prevent excessive seepage.

Where the foundation consists of highly pervious sand or sand-gravel mixture and any impervious clay layer is beyond economical reach with available equipment, a detailed investigation should be made. While such a foundation might be satisfactory insofar as stability is concerned, corrective measures will be required to prevent excessive seepage and possible failure.

A foundation consisting of or underlain by a highly plastic clay or unconsolidated material requires a very careful investigation and design in order to obtain stability.

Water impounded on bedrock foundations seldom gives cause for concern unless the rock contains seams, fissures or crevices through which water may escape at an excessive rate. Where rock is encountered in the foundation, a very careful investigation of the nature of the rock is required.

See Chapters 4 and 17 of this manual for further guidance.

FOUNDATION CUTOFFS

Where the foundation consists of pervious materials at or near the surface, with rock or impervious materials at a greater depth, seepage through the pervious layer should be reduced to prevent piping and excessive losses. Usually a cutoff joining the impervious stratum in the foundation with the base of the dam is needed.

The most common type of cutoff is one constructed of compacted clayey material. A trench is cut parallel to the centerline of the dam to a depth that extends well into the impervious layer. The trench is extended into and carried up the abutments of the dam as far as pervious material exists that might allow seepage under the embankment. The trench should have a bottom width of not less than 4 feet but adequate to allow use of equipment necessary to obtain proper compaction. Its sides should be no steeper than 1:1. The trench should be filled with successive thin layers of relatively impervious material, each layer being thoroughly compacted at near optimum moisture conditions before the succeeding layer is placed. Any water collected in the trench should be removed before backfill operations are started. (See Chapter 17 of this manual).

EMBANKMENT TOP WIDTH

A conservative top width for dams under 10 feet in height is 8 feet. The top width should be increased as the height of the dam increases. Table 11-4 contains recommended top widths for embankments of various heights. See State Standards and Specifications for local requirements.

Where the top of the embankment is to be used for a roadway, the top width should provide for a shoulder on each side of the traveled way to prevent raveling. The top width in such cases should not be less than 14 feet.

Table 11-4. Recommended top widths for earth embankments

Height of Dam (feet)	Top Width (feet)
Under 10	8
10 to 15	10
15 to 20	12
20 to 25	14

EMBANKMENT SIDE SLOPES

The side slopes of a dam depend primarily on the stability of the material in the embankment. The greater the stability of the fill material, the steeper the side slopes may be. The more unstable materials require flatter side slopes. Table 11-5 contains recommended maximum slopes for the upstream and downstream faces of dams constructed of various materials. See State Standards and Specifications for local requirements.

Table 11-5. Recommended side slopes for earth embankments

Fill Material		Side Slopes Horizontal to Vertical	
		Upstream	Downstream
Clay CH			
Clayey sand SC	Sandy clay CL	3 to 1	2 to 1
Silty clay CL	Silty sand SM	or	
Clayey gravel GC	Silty gravel GM	2½ to 1	2½ to 1
Silt ML or MH	Clayey silt ML	3 to 1	3 to 1

FREEBOARD

Freeboard is the added height of the dam provided as a safety factor to prevent waves or runoff from storms greater than the design frequency from overtopping the embankment. It is the vertical distance between the elevation of the water surface in the pond when the spillway is discharging at designed depth and the elevation of the top of the dam after all settlement has taken place. Where the maximum length of a pond is less than 660 feet, a freeboard of not less than 1.0 foot should be provided. For ponds with lengths between 660 and 1,320 feet the minimum freeboard should be 1.5 feet. For ponds up to ½ mile in length, the minimum freeboard should be 2.0 feet. See State Standards and Specifications for local requirements.

ALLOWANCE FOR SETTLEMENT

Settlement includes the consolidation of the fill materials and the consolidation of the foundation materials due to the weight of the dam and the increased moisture caused by the storage of water.

Settlement or consolidation depends on the character of the materials in the dam and foundation and on the methods and speed of construction. The design height of earth dams should be increased by an amount equal to the estimated settlement. This increase should not be less than 5 percent.

EARTHWORK COMPUTATION

The estimate of the volume of borrow required should include the dam, allowance for settlement, backfill for the cutoff trench, backfill for existing stream channels and holes in the foundation area, and any other embankment the contractor is required to perform.

Volume estimates for dams usually are made on the basis of cubic yards of earthfill in place. The common method of estimating the volume of earthfills is the "sum of end areas" method. With the fill heights, side slopes and top width established, the end area of the cross section at each station along the centerline may be obtained from Exhibit 11-6.

For example, assume that a dam has slopes of 3 to 1 on both upstream and downstream sides and a top width of 12 feet. For a point along the centerline where the fill height is 15.0 feet, the exhibit shows that the end area at that point is 675 + 180 or 855 square feet. The number of cubic yards of fill between two points on the centerline of the dam is equal to the sum of the end areas at the two points multiplied by the distance between these points and divided by (2 x 27) or 54. The total volume of earthfill in the dam is the sum of all such segments. A sample volume estimate illustrating the use of the "sum of end areas" method is presented in Table 11-6.

Table 11-6. Sample volume computations using "sum of end areas" method

Station	Ground Elevation	Fill Height (feet)	End Area 1/ (sq.ft.)	Sum of End Areas (sq.ft.)	Distance (feet)	Double Volume (cu.ft.)
0 + 50	35.0	0.0	0			
				44	18	792
+ 68	32.7	2.3	44			
				401	32	12,832
1 + 00	25.9	9.1	357			
				1066	37	39,442
+ 37	21.5	13.5	709			
				1564	16	25,024
+ 53	20.0	15.0	855			
				1730	22	38,060
+ 75	19.8	15.2	875			
				1781	25	44,525
2 + 00	19.5	15.5	906			
				1730	19	32,870
+ 19	20.3	14.7	824			
				1648	13	21,424
+ 32	20.3	14.7	824			
				1805	4	7,220
+ 36	18.8	16.2	981			
				2030	4	8,120
+ 40	18.2	16.8	1049			
				2064	3	6,192
+ 43	18.5	16.5	1015			
				1911	3	5,733
+ 46	19.6	15.4	896			
				1771	13	23,023
+ 59	19.8	15.2	875			
				1650	41	67,650
3 + 00	20.8	14.2	775			
				1023	35	35,805
+ 35	27.7	7.3	248			
				324	25	8,100
+ 60	31.6	3.4	76			
				76	36	2,736
3 + 96	35.0	0.0	0			
					Total 2/	379,548

1/ End areas based on 12-foot top width and 3 to 1 slopes on both sides.
2/ Double volume in cu.ft. is divided by 54 to obtain volume in cu.yds.

$\frac{379,548}{54}$ = 7,029 cu. yds.

Allowance for settlement (5%) = 351 cu. yds.

Total Volume = 7,380 cu. yds.

The sample volume estimate of 7,380 cubic yards includes only that volume of earth required to complete the dam itself. An estimate of the volume of earth required to backfill the core trench, old stream channels and other required excavation should be made and added to the estimate made for the dam. For example, assume that in addition to the volume shown in Table 11-6, there is a cutoff trench to be backfilled. The dimensions of the trench are as follows:

Average depth = 4.0 feet
Bottom width = 8.0 feet
Side slopes = 1 to 1
Length = 177 feet

The volume of backfill is computed as follows:

$$\text{End Area} = (8 \times 4) + (4 \times 4) = 32 + 16 = 48 \text{ square feet.}$$

$$\text{Volume} = \frac{48 \times 177}{27} = 315 \text{ cubic yards.}$$

Adding this to the volume required for the dam itself, the total volume becomes 7,380 + 315 = 7,695 cubic yards.

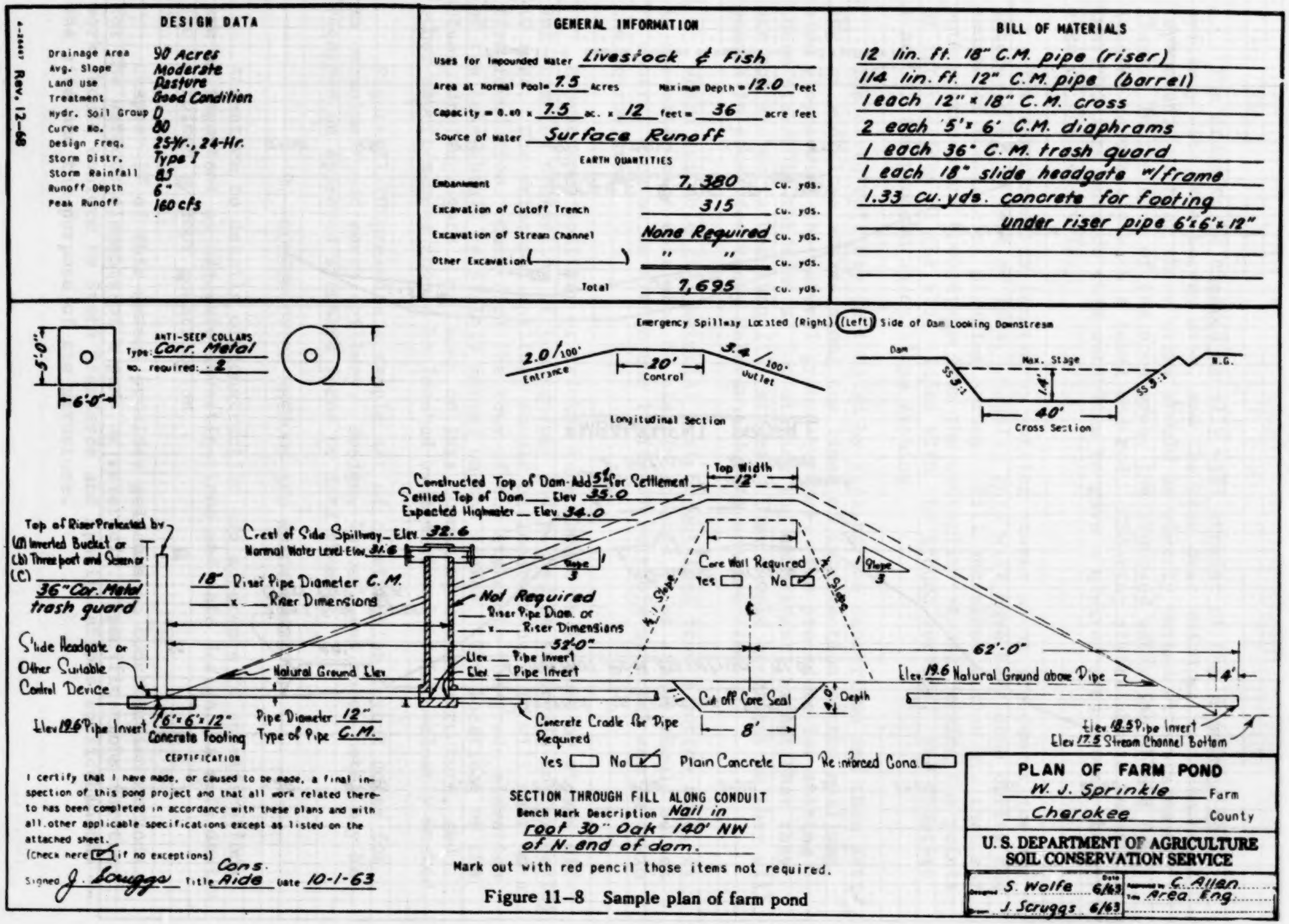
PLANS AND SPECIFICATIONS

All information developed during the design process should be recorded in the form of an engineering plan for the pond. This plan should show all pertinent elevations and dimensions of the dam, the dimensions and extent of the cutoff trench and other areas requiring backfill, the location and dimensions of the trickle tube and other planned appurtenances, and all other information pertinent to the construction of the dam. The plan should also include a bill of materials listing the quantity and type of all construction materials required. A sample plan of a farm pond embankment is shown in Figures 11-8 and 11-9.

Applicable engineering standards and construction specifications have been developed in each state for ponds and reservoirs. To obtain a quality job of construction the owner and contractor must understand all requirements. Both the owner and the contractor should be furnished copies of the plans and specifications.

8. STAKING FOR CONSTRUCTION

Staking is a means whereby the information on the farm pond plans is transmitted to the job site. This information will provide lines, grades, and elevations required for construction of the job in accordance with the plans. Consideration should be given to the contractor's wishes in staking so that he can make the most effective use of the stakes. The quality and appearance of the completed job will reflect the care and thoroughness exercised in the staking procedure.


5'-0"
6'-0"
Emergency Spillway Located (Right) (Left) Side of Dam Looking Downstream
2.0/100'
Entrance
20'
Control
3.4/100'
Outlet
Longitudinal Section
Dam
Max. Stage
1.4'
SS 3:1
SS 3:1
N.G.
40'
Cross Section
Top of Riser Protected by
(a) Inverted Bucket or
(b) Three post and Screen or
(C) 36" Cor. Metal trash guard
Slide Headgate or Other Suitable Control Device
Elev 19.6 Pipe Invert
6'×6'×12" Concrete Footing
Crest of Side Spillway _ Elev. 32.6
Normal Water Level Elev. 31.6
18" Riser Pipe Diameter C. M.
___ x ___ Riser Dimensions
Natural Ground Elev
Pipe Diameter 12"
Type of Pipe C.M.
Constructed Top of Dam-Add 5% for Settlement
Settled Top of Dam ___ Elev 35.0
Expected Highwater ___ Elev 34.0
Top Width 12'
Slope 1 3
Not Required
___ Riser Pipe Diam. or
___ x ___ Riser Dimensions
52'-0"
Elev ___ Pipe Invert
Elev ___ Pipe Invert
Concrete Cradle for Pipe Required
Yes ☐ No ☑ Plain Concrete ☐ Reinforced Conc. ☐
Core Wall Required
Yes ☐ No ☑
℄
1:1 Slope
1:1 Slope
Cut off Core Seal
Depth
8'
Slope 1 3
62'-0"
Elev 19.6 Natural Ground above Pipe
4'
Elev 18.5 Pipe Invert
Elev 17.5 Stream Channel Bottom
SECTION THROUGH FILL ALONG CONDUIT

4-26467 Rev. 12-68

DESIGN DATA

Drainage Area	90 Acres
Avg. Slope	Moderate
Land Use	Pasture
Treatment	Good Condition
Hydr. Soil Group	D
Curve No.	80
Design Freq.	25-Yr., 24-Hr.
Storm Distr.	Type I
Storm Rainfall	8.5
Runoff Depth	6"
Peak Runoff	160 cfs

GENERAL INFORMATION

Uses for Impounded Water Livestock & Fish

Area at Normal Pool = 7.5 Acres Maximum Depth = 12.0 feet

Capacity = 0.40 × 7.5 ac. × 12 feet = 36 acre feet

Source of Water Surface Runoff

EARTH QUANTITIES

Embankment	7,380	cu. yds.
Excavation of Cutoff Trench	315	cu. yds.
Excavation of Stream Channel	None Required	cu. yds.
Other Excavation (______)	" "	cu. yds.
Total	7,695	cu. yds.

BILL OF MATERIALS

12 lin. ft. 18" C.M. pipe (riser)
114 lin. ft. 12" C.M. pipe (barrel)
1 each 12" × 18" C.M. cross
2 each 5' × 6' C.M. diaphrams
1 each 36" C.M. trash guard
1 each 18" slide headgate w/frame
1.33 cu. yds. concrete for footing under riser pipe 6'×6'×12"

ANTI-SEEP COLLARS
Type: Corr. Metal
No. required: 2

CERTIFICATION

I certify that I have made, or caused to be made, a final inspection of this pond project and that all work related thereto has been completed in accordance with these plans and with all other applicable specifications except as listed on the attached sheet.
(Check here ☑ if no exceptions)

Signed J. Scruggs Title Cons. Aide Date 10-1-63

Bench Mark Description Nail in root 30" Oak 140' NW of N. end of dam.

Mark out with red pencil those items not required.

PLAN OF FARM POND
W. J. Sprinkle Farm
Cherokee County

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Designed S. Wolfe Date 6/63
Drawn J. Scruggs 6/63
Approved by C. Allen
Title Area Eng.

Figure 11–8 Sample plan of farm pond

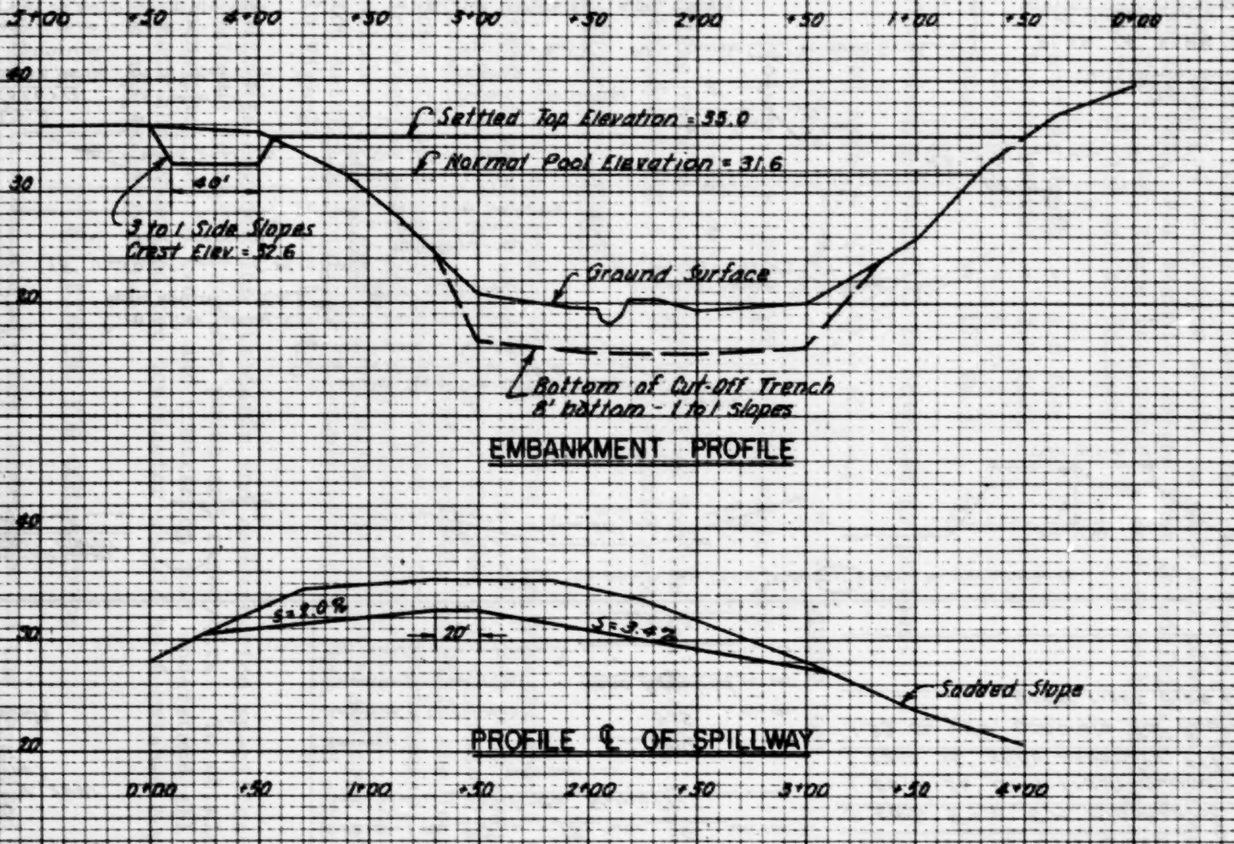


Figure 11–9 Sample profiles of embankment and spillway

The areas to be cleared usually will consist of the damsite, the spillway site, the borrow area, and the area over which water is to be impounded. Each of these areas should be clearly marked with stakes or flags. In the case of the pond area, the proposed waterline should be located accurately with a level and rod. Clearing stakes should be at least 15 feet outside this waterline to give a cleared area around the edge of the reservoir.

The embankment is located by setting stakes along its centerline at intervals of 50 feet or less. Usually this will have been done during the course of the initial planning survey. Fill and slope stakes are then set both upstream and downstream from the centerline stakes marking the points of intersection of the side slopes with the ground surface. See Chapters 1 and 17 for procedures on slope staking.

The earth spillway is located by staking the centerline and then setting cut and slope stakes along the lines of intersection of the spillway side slopes with the natural ground surface. The procedure for setting these stakes is the same as for staking the embankment, except that they are cut stakes rather than fill stakes. They should be offset so they will remain in place for ready reference during construction.

Where suitable fill material must be obtained from a borrow area, it is essential that this area be clearly located. Cut stakes should be set to control excavation within the limits of suitable material and to drain the borrow area.

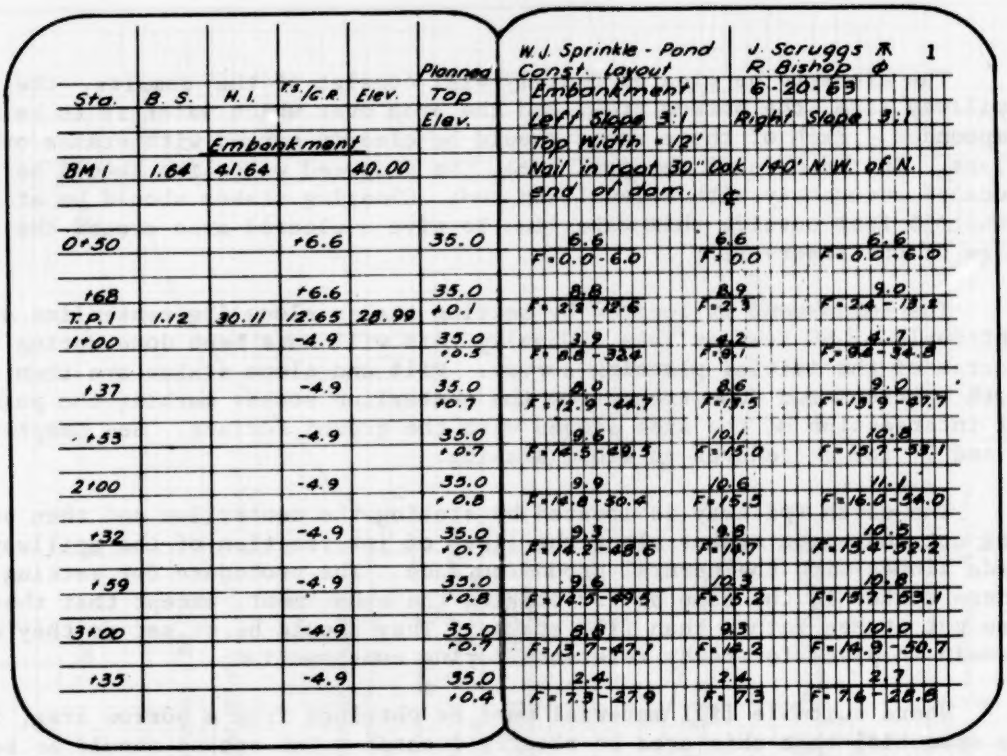
A principal spillway or trickle tube should be located by stakes offset from the centerline of the conduit and placed at intervals not exceeding 50 feet. The principal spillway should be located where it will rest on a firm foundation. Cuts from the tops of the stakes to the grade elevation of the tube should be plainly marked on the stakes. The locations of the riser, drainage gate, antiseep collars, conduit, outlet structure, and other appurtenances should be located by additional stakes, clearly marked.

Figure 11-10 presents a sample set of construction layout notes for an embankment and earth spillway. Design, layout, and check notes may be recorded on approved standard forms or data sheets.

9. CONSTRUCTION METHODS AND SPECIFICATIONS

Attention to details of construction and adherence to specifications are as important as adequate investigations and safe design. A safe design can be ruined by poor construction.

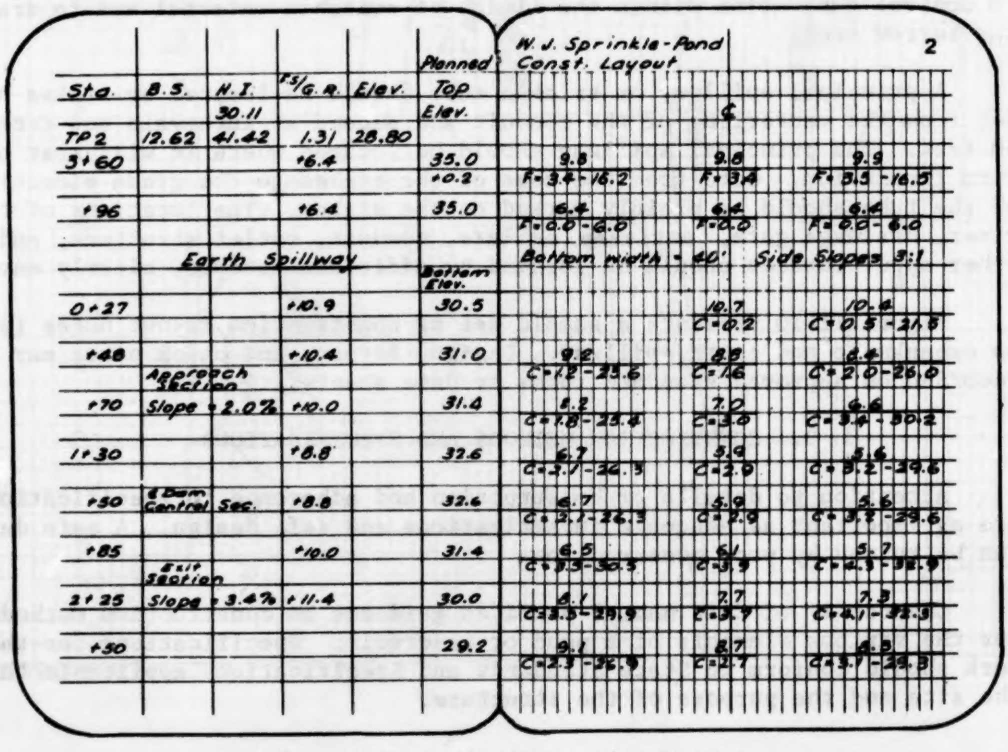
Chapter 17 of this manual provides guidance on construction methods for the various elements of a pond or reservoir. Specifications for the work should conform to State Standards and Specifications applicable to the site and the purpose of the structure.



W. J. Sprinkle - Pond
Const. layout
J. Scruggs ⊼
R. Bishop ϕ
1

Embankment 6-20-63
Left Slope 3:1 Right Slope 3:1
Top Width = 12'
Nail in root 30" Oak 140' N.W. of N. end of dam.

Sta.	B. S.	H. I.	F.S./G.R.	Elev.	Planned Top Elev.		℄	
		Embankment						
BM 1	1.64	41.64		40.00				
0+50			+6.6		35.0	6.6 F=0.0-6.0	6.6 F=0.0	6.6 F=0.0-6.0
+68			+6.6		35.0 +0.1	8.8 F=2.2-12.6	8.9 F=2.3	9.0 F=2.4-13.2
T.P. 1	1.12	30.11	12.65	28.99				
1+00			-4.9		35.0 +0.5	3.9 F=8.8-32.4	4.2 F=9.1	4.7 F=9.8-34.8
+37			-4.9		35.0 +0.7	8.0 F=12.9-44.7	8.6 F=13.5	9.0 F=13.9-47.7
+53			-4.9		35.0 +0.7	9.6 F=14.5-49.5	10.1 F=15.0	10.8 F=15.7-53.1
2+00			-4.9		35.0 +0.8	9.9 F=14.8-50.4	10.6 F=15.5	11.1 F=16.0-54.0
+32			-4.9		35.0 +0.7	9.3 F=14.2-48.6	9.8 F=14.7	10.5 F=15.4-52.2
+59			-4.9		35.0 +0.8	9.6 F=14.5-49.5	10.3 F=15.2	10.8 F=15.7-53.1
3+00			-4.9		35.0 +0.7	8.8 F=13.7-47.1	9.3 F=14.2	10.0 F=14.9-50.7
+35			-4.9		35.0 +0.4	2.4 F=7.3-27.9	2.4 F=7.3	2.7 F=7.6-28.8

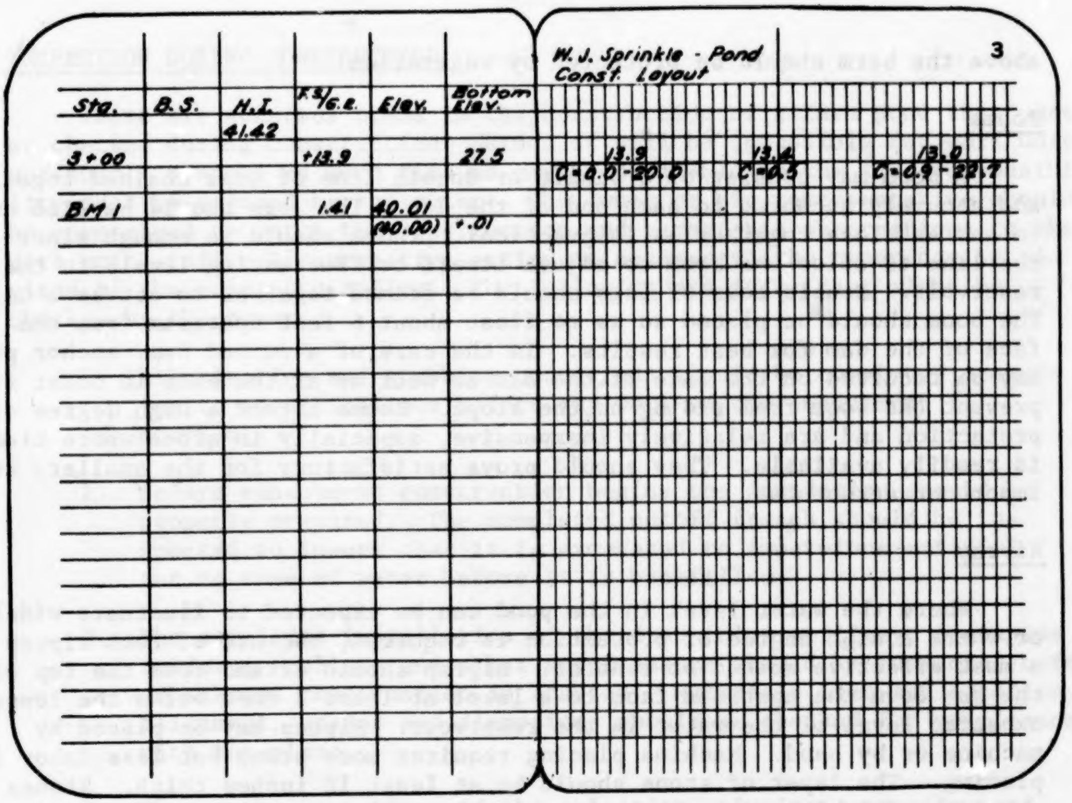


W. J. Sprinkle-Pond
Const. Layout
2

Sta.	B. S.	H. I.	F.S./G. R.	Elev.	Planned Top Elev.		℄	
		30.11						
TP 2	12.62	41.42	1.31	28.80				
3+60			+6.4		35.0 +0.2	9.8 F=3.4-16.2	9.8 F=3.4	9.9 F=3.5-16.5
+96			+6.4		35.0	6.4 F=0.0-6.0	6.4 F=0.0	6.4 F=0.0-6.0
	Earth Spillway				Bottom Elev.	Bottom width = 40'		Side Slopes 3:1
0+27			+10.9		30.5		10.7 C=0.2	10.4 C=0.5-21.5
+48			+10.4		31.0	9.2 C=1.2-25.6	8.8 C=1.6	8.4 C=2.0-26.0
	Approach Section							
+70	Slope = 2.0%		+10.0		31.4	8.2 C=1.8-25.4	7.0 C=3.0	6.6 C=3.4-30.2
1+30			+8.8		32.6	6.7 C=2.1-26.3	5.9 C=2.9	5.6 C=3.2-29.6
+50	℄ Dam Control Sec.		+8.8		32.6	6.7 C=2.1-26.3	5.9 C=2.9	5.6 C=3.2-29.6
+85			+10.0		31.4	6.5 C=3.5-30.5	6.1 C=3.9	5.7 C=4.3-32.9
	Exit Section							
2+25	Slope = 3.4%		+11.4		30.0	8.1 C=3.3-29.9	7.7 C=3.7	7.3 C=4.1-32.3
+50					29.2	9.1 C=2.3-26.9	8.7 C=2.7	8.3 C=3.1-29.3

Figure 11–10 Construction layout notes.

(Sheet 1 of 2)



Sta.	B.S.	H.I.	F.S./G.R.	Elev.	Bottom Elev.
		41.42			
3+00			+13.9		27.5
BM 1			1.41	40.01 (40.00)	+.01

W. J. Sprinkle - Pond
Const. Layout
3

13.9
C-0.0-20.0

13.4
C-0.5

13.0
C-0.9-22.7

Figure 11–10 Construction layout notes (Sheet 2 of 2)

10. POND AND RESERVOIR PROTECTION

A farm pond should not be considered complete until proper protection from erosion, wave action, livestock and other sources of damage has been provided. Ponds that lack such protection may be short-lived, and the cost of maintenance is usually high.

PROTECTION AGAINST EROSION

In most areas the exposed surfaces of the dam, spillway, borrow areas and other disturbed surfaces can be protected against erosion by establishing a good cover of sod-forming grass in accordance with the local Technical Guide.

PROTECTION FROM WAVE ACTION

Occasionally there is need for better protection against wave action than will be provided by a grass cover. Some methods used to provide this protection are earth berms, log booms, and rock riprap.

Berms

A berm, 8 to 10 feet in width, located at normal pond level often will provide adequate protection from wave action. The face of the dam

above the berm should be protected by vegetation.

Booms

A boom may consist of a single or double line of logs chained together and securely anchored to each end of the dam. The logs should be tied end to end as close together as is practical. There should be enough slack in the line to allow the boom to adjust itself to fluctuating levels in the reservoir. Double rows of logs should be framed together to act as a unit. The boom should be placed so as to float about 6 feet upstream from the face of the dam for best results. In the case of a curved dam, anchor posts may be required on the face of the dam as well as at the ends in order to prevent the boom from riding on the slope. Booms afford a high degree of protection and are relatively inexpensive, especially in areas where timber is readily available. They should prove satisfactory for the smaller, less important structures.

Riprap

Where the water level in the pond can be expected to fluctuate widely or where a high degree of protection is required, the use of rock riprap is a most effective method of control. Riprap should extend from the top of the dam down the upstream face to a level at least 3 feet below the lowest expected level of the water in the reservoir. Riprap may be placed by machine or by hand. Machine placing requires more stone but less labor in placing. The layer of stone should be at least 12 inches thick. Stones should be durable and large enough not to be displaced by waves.

Where riprap is not continuous to the upstream toe, a berm should be provided on the upstream face to support the layer of riprap. See Chapter 17 for guidance on installing riprap.

Other Methods

Other methods include increasing the top width of the dam, flattening the front slope of the embankment, and applying a layer of coarse sand and gravel on a 10:1 slope. These methods are applicable to arid areas where vegetation is not dependable and rock and timber is not readily available.

FENCING

The complete fencing of embankment-type ponds is recommended where livestock are grazed or fed in adjacent areas. The fencing provides the protection needed to develop and maintain vegetative cover. When combined with a watering facility below the dam, fencing provides good drinking water and eliminates the danger of pollution by livestock. Fencing also improves wildlife environment.

11. CHECKING FOR COMPLIANCE WITH STANDARDS

While both the owner and the contractor have responsibilities for compliance with standards, inspection is also required if high standards are to be maintained.

INSPECTION DURING CONSTRUCTION

There are numerous items in the construction of a farm pond that must be checked during construction. Since it will be impossible for work unit personnel to spend as much time as may be desirable on the job, responsibility must be assumed by the owner. The owner or his representative should be encouraged to watch the construction and report his observations to the work unit staff. If corrective action is necessary, the owner can be advised of the course to follow. The following are items that might be checked by the owner.

1. All clearing and grubbing operations should be completed according to specifications before any work on the embankment is started.
2. Before embankment construction begins the foundation should be properly prepared. The completed cutoff trench should be inspected to insure that it is excavated to impervious material and is free of water before it is backfilled.
3. The completed installation of the drop inlet spillway, drainpipe antiseep collars and other appurtenance should be inspected before embankment construction is started. Materials used and location, alignment, grades and dimensions should be checked for compliance with the plans.
4. The earth excavation and the selecting, placing, spreading and compacting of the material in the embankment should be inspected frequently to insure that the specifications are met.

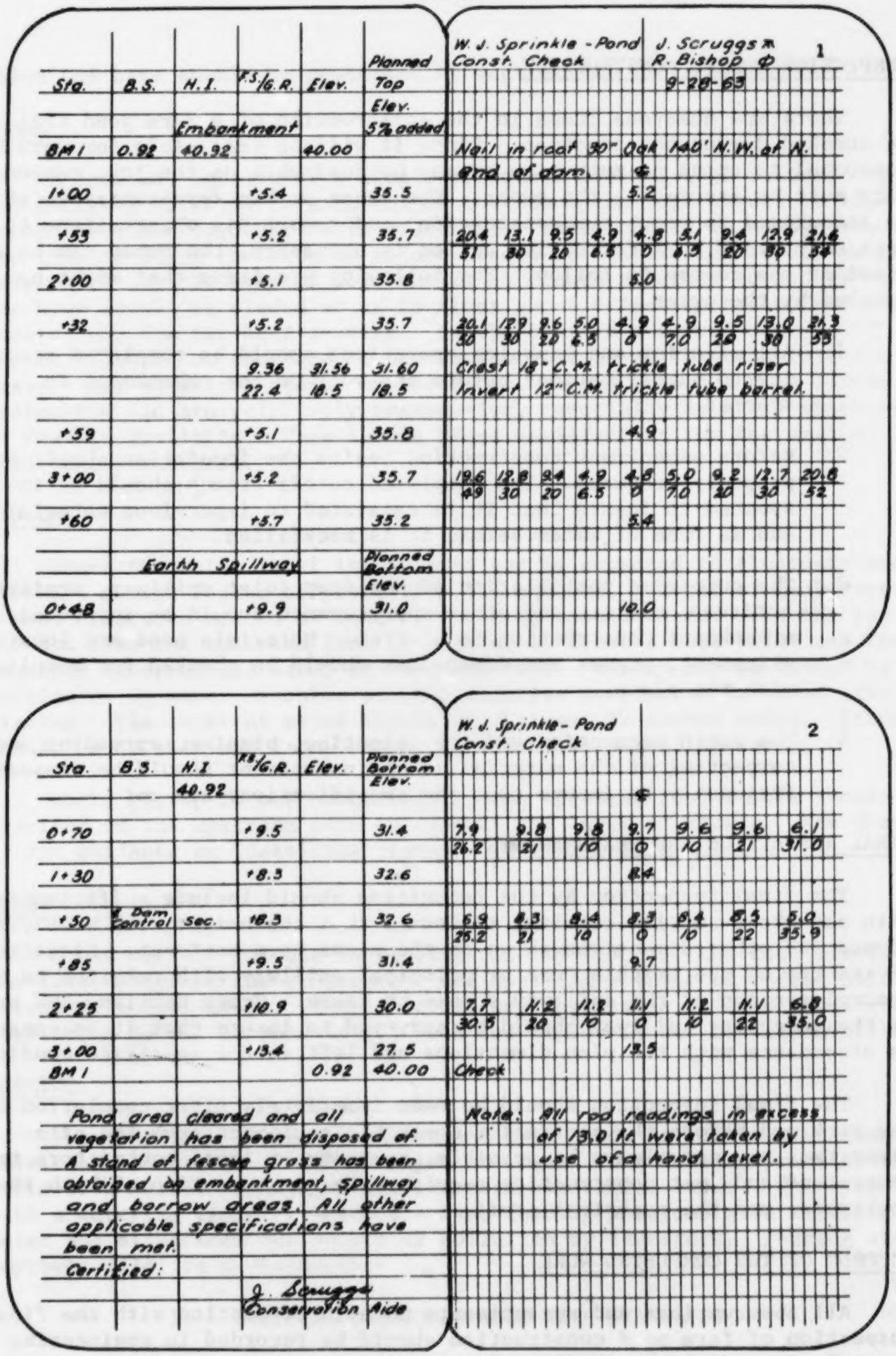
FINAL INSPECTION AND MEASUREMENTS

The final inspection by the technician should include sufficient profile and cross-section readings to insure that the height, top width, side slopes and other dimensions shown on the plans have been met. Elevations of the top of the trickle tube or principal spillway with relation to the control section of the spillway should be taken. Cross sections and profile of the emergency spillway should be surveyed to insure that it is constructed in accordance with the plan dimensions and left in the specified condition.

The final inspection should be made immediately after completion of the work and before the contractor moves his equipment from the site. Since this may not always be possible, training of local contractors to understand and meet construction requirements can save time of both the contractor and the technical staff.

RECORDS OF THE COMPLETED WORK

All observations and measurements made in connection with the final inspection of farm pond construction should be recorded in engineering loose-leaf or field notebooks and noted in red on the construction plans. A sample of the measurements required is shown in the Construction Check Notes, Figure 11-11. The notes should be filed in accordance with State



Sta.	B.S.	H.I.	F.S./G.R.	Elev.	Planned Top Elev. 5% added
		Embankment			
BM1	0.92	40.92		40.00	
1+00			+5.4		35.5
+53			+5.2		35.7
2+00			+5.1		35.8
+32			+5.2		35.7
			9.36	31.56	31.60
			22.4	18.5	18.5
+59			+5.1		35.8
3+00			+5.2		35.7
+60			+5.7		35.2
	Earth Spillway				Planned Bottom Elev.
0+48			+9.9		31.0

W. J. Sprinkle - Pond Const. Check
J. Scruggs ⊼
R. Bishop Φ
1
9-28-63

Nail in root 30" Oak 140' N.W. of N. end of dam.

℄

5.2

$\frac{20.4}{51}$ $\frac{13.1}{30}$ $\frac{9.5}{20}$ $\frac{4.9}{6.5}$ $\frac{4.8}{0}$ $\frac{5.1}{6.5}$ $\frac{9.4}{20}$ $\frac{12.9}{30}$ $\frac{21.6}{54}$

5.0

$\frac{20.1}{30}$ $\frac{12.9}{30}$ $\frac{9.6}{20}$ $\frac{5.0}{6.5}$ $\frac{4.9}{0}$ $\frac{4.9}{7.0}$ $\frac{9.5}{20}$ $\frac{13.0}{30}$ $\frac{21.3}{53}$

Crest 18" C.M. trickle tube riser
Invert 12" C.M. trickle tube barrel.

4.9

$\frac{19.6}{49}$ $\frac{12.8}{30}$ $\frac{9.4}{20}$ $\frac{4.9}{6.5}$ $\frac{4.5}{0}$ $\frac{5.0}{7.0}$ $\frac{9.2}{20}$ $\frac{12.7}{30}$ $\frac{20.8}{52}$

5.4

10.0

Sta.	B.S.	H.I	F.S./G.R.	Elev.	Planned Bottom Elev.
		40.92			
0+70			+9.5		31.4
1+30			+8.3		32.6
+50	℄ Dam Control	Sec.	+8.3		32.6
+85			+9.5		31.4
2+25			+10.9		30.0
3+00			+13.4		27.5
BM1				0.92	40.00

Pond area cleared and all
vegetation has been disposed of.
A stand of fescue grass has been
obtained on embankment, spillway
and borrow areas. All other
applicable specifications have
been met.
Certified:
J. Scruggs
Conservation Aide

W. J. Sprinkle - Pond Const. Check
2

℄

$\frac{7.9}{26.2}$ $\frac{9.8}{21}$ $\frac{9.8}{10}$ $\frac{9.7}{0}$ $\frac{9.6}{10}$ $\frac{9.6}{21}$ $\frac{6.1}{31.0}$

8.4

$\frac{6.9}{25.2}$ $\frac{8.3}{21}$ $\frac{8.4}{10}$ $\frac{8.3}{0}$ $\frac{8.4}{10}$ $\frac{8.5}{22}$ $\frac{5.0}{35.9}$

9.7

$\frac{7.7}{30.5}$ $\frac{11.2}{20}$ $\frac{11.2}{10}$ $\frac{11.1}{0}$ $\frac{11.2}{10}$ $\frac{11.1}{22}$ $\frac{6.8}{35.0}$

13.5

Check

Note: All rod readings in excess of 13.0 ft. were taken by use of a hand level.

Figure 11–11 Construction check notes.

memorandums. Some State laws require a formal completion report and as-built plans.

12. POND AND RESERVOIR MAINTENANCE

A farm pond must be adequately maintained if its purposes are to be realized throughout its expected life. Severe damage to, or total failure of, dams and spillways have been caused by lack of maintenance. For these reasons, it is important that the owner carry out the measures described in the following paragraphs.

INSPECTION AND REPAIRS

Farm ponds should be inspected periodically, especially after heavy rains, to determine the need for minor repairs. Immediate repair often eliminates the need for more costly repairs later.

Rills on the slopes of the dam and washes in the earth spillway should be filled with suitable material and thoroughly compacted. These areas should be reseeded or resodded and fertilized as needed. Should the upstream face of the earthfill wash or slough due to wave action, protective devices such as booms or riprap should be installed. If there is seepage through or under the dam, an engineer should be consulted to recommend proper corrective measures.

The vegetative cover on the dam and earth spillway should be maintained by mowing and fertilizing when needed. Proper mowing prevents the formation of woody growth and tends to develop a cover and root system more resistant to runoff. Fences should be kept in good repair.

Appurtenances such as trickle tubes, trash racks, outlet structures, valves and watering troughs should be kept free of trash.

Burrowing animals may cause severe damage to farm pond dams or spillways. If such damage remains unrepaired it may lead to failure. A thick layer of sand or gravel on the fill discourages burrowing. Poultry netting can be used effectively, but it will rust out and need replacement. If these pests persist, aggressive trapping and poisoning should be undertaken.

SANITATION

It is desirable to keep the water in a farm pond as clean and unpolluted as possible. Unnecessary trampling by livestock should not be permitted. Where it is not practical to exclude livestock from a pond by fencing, small rocks or gravel should be used to pave the approaches to the water. Drainage from barn lots, feed yards, bedding grounds, outhouses, septic tanks, or other sources of contamination should be diverted from farm ponds. This is especially important where the water supply is to be used for harvesting ice, fish and wildlife development, or recreation.

In areas where surface waters encourage the breeding of mosquitoes, the pond should be stocked with top-feeding fish. Gambusia minnows are particularly effective. Where malaria prevails, aquatic growth and shoreline vegetation should not be permitted, and special precautions should be observed in the planning, construction, and operation of the pond. Most states in malarial sections have health regulations covering these precautions which should be followed.

In some areas the development of algae and other forms of plant life in reservoirs may become objectionable. Generally, these are harmless, but they may cause disagreeable tastes or odors, encourage bacterial development, and make the pond unsightly. Treatment with bluestone (copper sulfate) will check the development of algae. The usual dosage is 2 or 3 pounds per million gallons of water, well distributed throughout the reservoir. Overdosage may be harmful to both wildlife and livestock.

PART III - EXCAVATED PONDS

An excavated pond is the simplest type to construct and is the only type that can be constructed in relatively flat terrain. The fact that the capacity of these ponds is obtained almost solely from excavation limits their practical size. Since excavated ponds can be constructed to expose a minimum water surface area in proportion to volume, they are advantageous where evaporation losses are high and water is scarce. See Figures 11-12 and 11-13.

1. TYPES OF EXCAVATED PONDS

Excavated farm ponds may be divided into two types: those fed by surface runoff; and those fed by ground water aquifers, usually layers of sand and gravel. In some instances a pond may be fed from both of these sources.

2. LOCATION OF EXCAVATED PONDS

The location of excavated ponds depends on the purpose for which the water is to be used and on other factors discussed previously in this chapter.

Excavated ponds fed by surface runoff may be located on almost any type of topography. They are, however, most satisfactory and most commonly used in areas with comparatively flat terrain. A pond may be located in a broad natural drainageway or to one side of a drainageway if the runoff can be diverted into the pond. The low point of a natural depression is often a good location for an excavated pond. After the pond is filled, excess runoff escapes through natural drainageways. Thus, locations with favorable discharge conditions should be selected.

An excavated pond fed by ground water aquifers can be located only where shallow underground flow exists or where the permanent water table is within a few feet of the surface. See Figure 11-14.

3. SOILS INVESTIGATION

Where the excavated pond is to be fed by surface runoff, relatively impervious soil at the site is essential to avoid excess seepage losses. Clays and silty clays extending below the planned reservoir depth are most desirable, and sites with sandy clays usually prove satisfactory. Sites where soils are porous or are underlain by sands or gravel should be avoided unless the owner is prepared to bear the expense of an artificial lining. Soils underlain by limestone containing crevices, sinks or channels should be avoided.

The performance of nearby existing ponds in a similar soil is a good indicator of the suitability of a proposed site. Such observations of existing ponds should be supplemented by subsurface investigations. Some indication of the permeability of the soil may be obtained by filling the test holes with water and observing the seepage characteristics of the material.

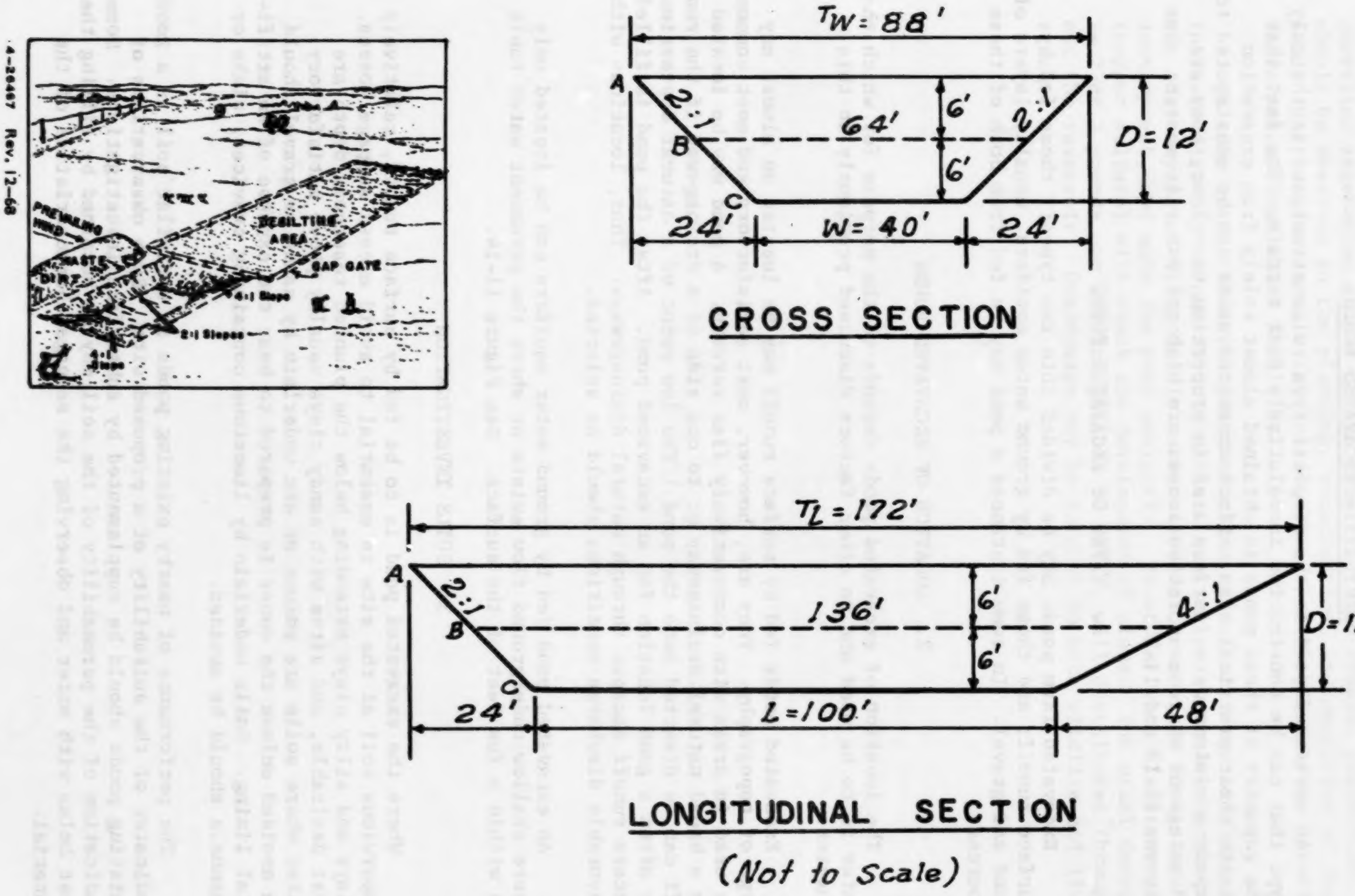

DESILTING AREA
GAP GATE
4:1 Slope
2:1 Slopes
4:1 Slope
PREVAILING WIND
WASTE DIRT
4-20467 Rev. 12-68
TW= 88'
A
B
C
2:1
2:1
64'
6'
6'
D=12'
24'
W= 40'
24'
CROSS SECTION
TL = 172'
A
B
C
2:1
136'
6'
6'
4:1
D=12'
24'
L=100'
48'
LONGITUDINAL SECTION
(Not to Scale)

Figure 11–12 Excavated pond and typical sections. Note fenced desilting area above pond.

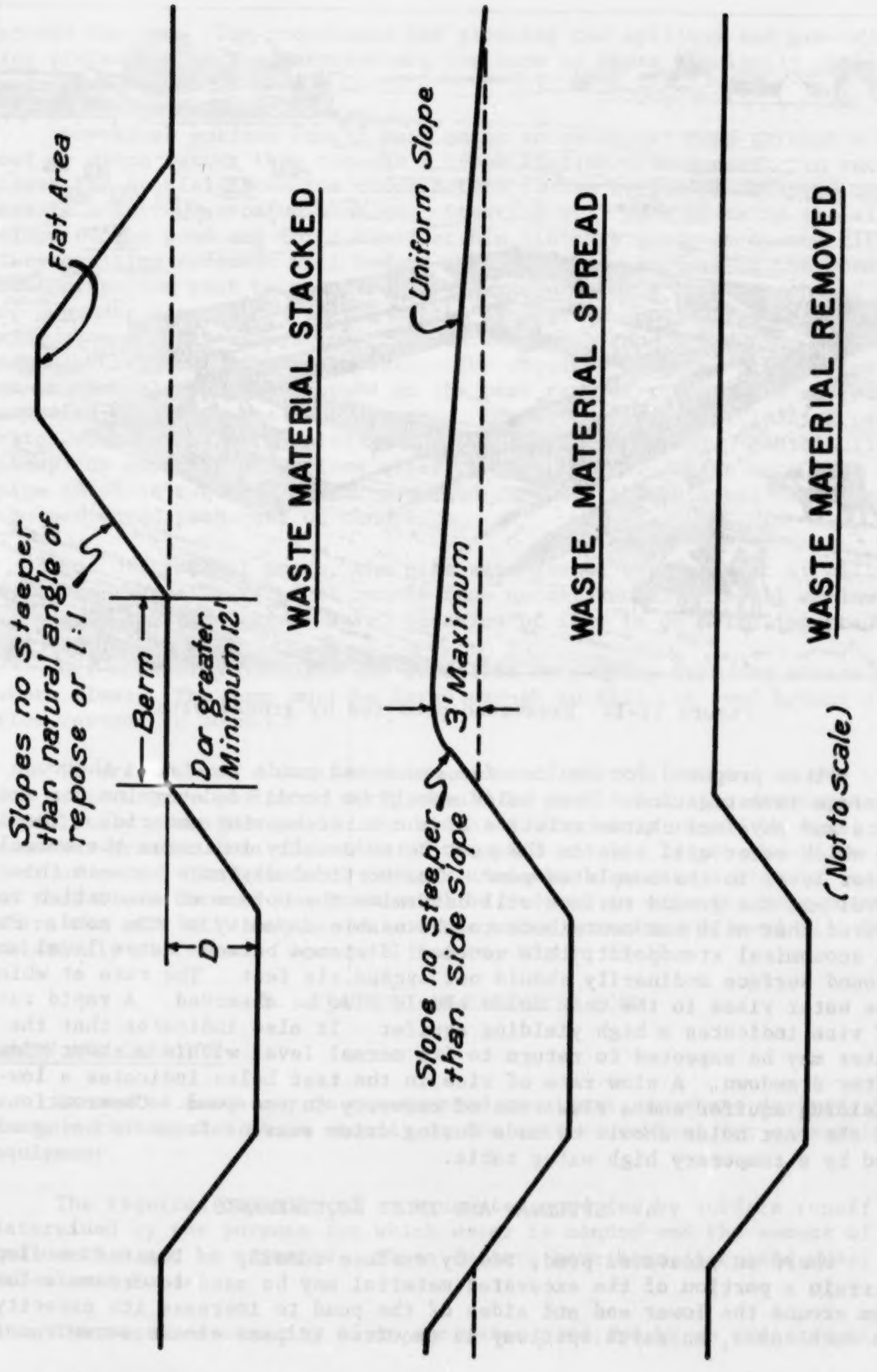

Slopes no Steeper than natural angle of repose or 1:1
Flat Area
Berm
D or greater Minimum 12'
D
WASTE MATERIAL STACKED
Slope no Steeper than Side Slope
Uniform Slope
3' Maximum
WASTE MATERIAL SPREAD
WASTE MATERIAL REMOVED
(Not to scale)

Figure 11–13 Cross sections of excavated pond showing methods of waste material disposal.

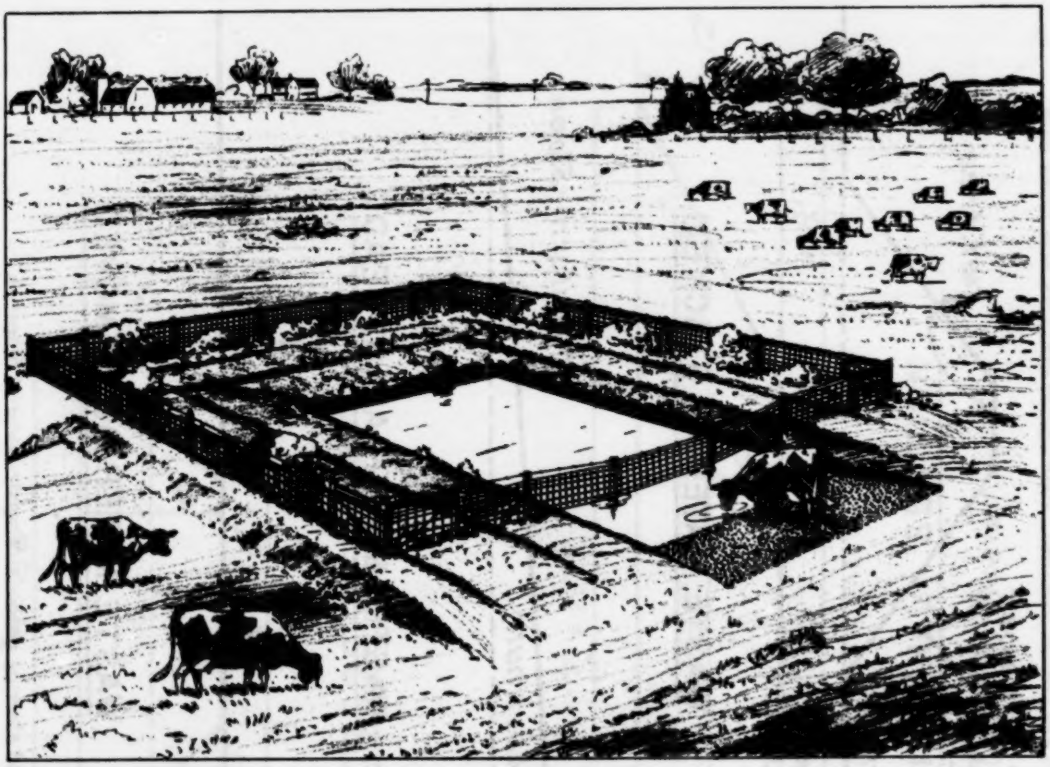


Figure 11-14 Excavated pond fed by ground water.

Sites proposed for aquifer-fed excavated ponds require a thorough subsurface investigation. Test holes should be bored to determine the existence and physical characteristics of the water-bearing material. The level to which water will rise in the test holes usually indicates the normal water level in the completed pond. The vertical distance between this level and the ground surface will determine the volume of excavation required that will not contribute to the usable capacity of the pond. From an economical standpoint, this vertical distance between water level and ground surface ordinarily should not exceed six feet. The rate at which the water rises in the test holes should also be observed. A rapid rate of rise indicates a high yielding aquifer. It also indicates that the water may be expected to return to its normal level within a short time after drawdown. A slow rate of rise in the test holes indicates a low-yielding aquifer and a slow rate of recovery in the pond. Observations of the test holes should be made during drier seasons to avoid being misled by a temporary high water table.

4. SPILLWAY AND INLET REQUIREMENTS

Where an excavated pond, fed by surface runoff, is located on sloping terrain a portion of the excavated material may be used to create a low dam around the lower end and sides of the pond to increase its capacity. In such cases, an earth spillway is required to pass excess storm runoff around the dam. The procedures for planning the spillway and providing for protection against erosion are the same as those previously discussed under Embankment Ponds.

Sometimes surface runoff must enter an excavated pond through a channel or ditch rather than through a broad shallow drainageway. In such cases the overfall from the ditch bottom to the bottom of the pond may create a serious erosion problem. Scouring will take place in the side slope of the pond and for a considerable distance upstream in the ditch. The resulting sediment will reduce the depth and capacity of the pond. Protection can best be provided by the use of one or more lengths of pipe of adequate size placed in the ditch, backfilled, and extended over the side slope of the excavation. The extended portion of the pipe may be cantilevered over timber supports. The required diameter of the pipe for an on-channel pond will depend on the peak rate of runoff that may be expected to occur once in ten years. The procedure for estimating peak rates of runoff is presented in Chapter 2 of this manual. Exhibit 11-7 shows the capacity of various sizes of pipe inlets. Where more than one pipe inlet is required, their combined capacity should equal or exceed the estimated peak rate of runoff.

For off-channel ponds, the pipe size should be such that it will divert from the channel sufficient runoff from normal annual rainfall or low flows to supply the reservoir. Here, duration of flow is of prime importance.

Off-channel ponds also can be filled by pumping from the stream during storm flows. The pump must be large enough to fill the pond before stream flow returns to normal.

In areas where a considerable amount of silt is carried by the inflowing water a grassed filter strip should be provided in the drainageway immediately above the pond. The width of this strip should be equal to or somewhat greater than the width of the pond and its length should be 100 feet or more. The perennial grasses used should create a high "n" value so that flows through the grass will be reduced in velocity to a point where the silt will settle out and the water entering the pond will be relatively silt-free. See small insert, Figure 11-12.

5. PLANNING AN EXCAVATED POND

SHAPE AND CAPACITY

Excavated ponds may be constructed to almost any shape desired, however, a rectangular shape usually is the most convenient for excavating equipment.

The required capacity of an excavated pond fed by surface runoff is determined by the purpose for which water is needed and the amount of inflow that can be expected. These factors have been discussed under Embankment Ponds.

The required capacity of an excavated pond fed by an underground water-bearing layer is difficult to determine since the estimated rate of inflow into the pond can rarely be estimated with reasonable accuracy. For this reason the pond should be constructed in such manner that it can be enlarged if the original capacity proves inadequate.

SELECTING POND DIMENSIONS

The selected dimensions of an excavated pond will depend upon the required capacity. Excavated ponds fed by surface runoff should have a depth equal to or greater than the minimum required by State Standards and Specifications. Where an excavated pond is fed from ground water, the depth should extend well into the water-bearing material. The maximum depth will depend on the climatic conditions, the nature of the material to be excavated, and the type of equipment to be used in excavating the pond.

The width of an excavated pond will not ordinarily be limited, except that the type and size of the excavating equipment may become a limiting factor. For example, if a dragline is used the length of the boom will determine the maximum width of excavation that can be made with proper placement of the waste material.

The minimum length of the pond should be that needed to obtain the required pond capacity. However, this length may need to be increased to meet the needs of the excavating equipment, such as a carryall.

The side slopes of an excavated pond should not be steeper than the natural angle of repose of the material being excavated. This angle will vary with different soils, but in most cases the side slopes should be flatter than 1:1.

Where the water is to be used for watering livestock, a ramp with a slope of 4:1, or flatter, should be provided at one or both ends for access. Regardless of the intended use of the water, these flat slopes at the ends of the pond are necessary when tractor-pulled scrapers or bulldozers are used for construction.

ESTIMATING THE VOLUME OF AN EXCAVATED POND

After the dimensions and side slopes of the pond have been selected, it is usually necessary to prepare an estimate of the volume of excavation. Such an estimate determines the cost of the pond and serves as a basis for payment if the work is done by contract.

The volume of excavation required can be estimated with sufficient accuracy by use of the prismoidal formula:

$$V = \frac{(A + 4B + C)}{6} \times \frac{D}{27}, \text{ where:}$$

V = Volume of excavation, in cubic yards

A = Area of the excavation at the ground surface, in square feet

B = Area of the excavation at the mid-depth point (1/2 D), in square feet

C = Area of the excavation at the bottom of the pond, in square feet.

D = Average depth of the pond, in feet

27 = Factor converting cubic feet to cubic yards

As an example, assume a pond with a depth, D, of 12 feet; a bottom width, W, of 40 feet, and a bottom length, L, of 100 feet as shown in Figure 11-12.

The side slope at the ramp end is 4:1 and the remaining slopes are 2:1. The volume excavation, V, is computed as follows:

Top length = 12(2) + 12(4) + 100 = 172 feet
Top width = 12 (2)(2) + 40 = 88 feet
A = 88 x 172 = 15,136 square feet

Mid-length = 6(2) + 6 (4) + 100 = 136 feet
Mid-width = 6(2)(2) + 40 = 64 feet
4B = 4(64 x 136) = 34,816 square feet
C = 40 x 100 = 4,000 square feet
(A + 4B + C) = 53,952 square feet

$$\text{Then } V = \frac{53{,}952}{6} \times \frac{12}{27} = 3{,}996 \text{ cubic yards (or 4,000 cubic yards)}$$

Assuming that the normal water level in the pond is at the ground surface, the volume of water that can be stored in the pond is 4,000 cu. yds. x .00062, or 2.48 acre feet. To convert to gallons multiply 4,000 cu. yds. by 202.0 to get 808,000 gallons. The same procedure is used to compute the volume of water that can be stored in the pond when the normal water level is below the ground surface. In this case, the value assigned to the depth, D, is the actual depth of water in the pond rather than the depth of excavation.

DISPOSAL OF WASTE MATERIAL

The placement or disposal of the excavated material should be planned in advance of construction. Proper disposal will prolong the useful life of the pond, improve its appearance and facilitate maintenance and establishment of vegetation. The waste material may be stacked, spread, or removed from the site as conditions warrant.

The waste material, when not removed from the site, should be placed in a manner that its weight will not endanger the stability of the pond side slopes and the rainfall will not wash the material back into the pond. Stacked material should be placed in a uniform bank with side slopes no steeper than the natural angle of repose of the soil. A berm with a width equal to the depth of the pond, but not less than 12 feet should be left between the toe of the waste bank and the edge of the pond. In the case of large ponds, it is often desirable to stack the waste material along two sides of the pond to reduce the height of the banks. In the Northern Plains the waste banks may be placed on the windward side of the pond to serve as a snow fence for collecting drifts in the pond. See Figure 11-12.

Banks placed in this manner may also reduce evaporation losses by breaking the force of prevailing winds across the pond.

Spreading the waste material along one or both sides of a pond has several advantages. The pressure on the excavated slopes is reduced, establishment of vegetation is enhanced, and the general appearance of the pond is improved. The waste material should be spread to a height of no more than 3 feet with the surface graded to a uniform slope away from the pond. The pond side slope of the spread material should be no steeper than the excavated slopes. Rocky, infertile, or otherwise unproductive material, should not be spread over productive areas. Sometimes the waste material may be used for filling nearby low areas in a field or in the construction of farm roads.

Figure 11-13 shows cross sections of a pond illustrating the methods of placement and disposal of waste material.

6. EXCAVATED POND CONSTRUCTION

The pond site and waste areas should first be cleared of all woody vegetation. The limits of the excavation and spoil placement areas should be staked, and the depth of cut from the ground surface to the pond bottom should be indicated on the stakes.

Excavation and the placement of the waste material are the principal items of work required in the construction of this type of pond. The type of equipment used will depend on climate and physical conditions at the site, and on the equipment available.

In areas of low rainfall almost any type of equipment may be used and the choice of type is determined by availability. The most commonly used are tractor-pulled wheeled scrapers, draglines, and bulldozers. Due to its inefficiency in transporting material, the use of a bulldozer for excavation is usually limited to relatively small ponds.

In high-rainfall areas and in areas where a ground water table exists within the limits of excavation, the dragline is most commonly used since it can operate satisfactorily in water. The dragline is used exclusively for ponds fed by ground water aquifers.

The excavation should be made and the waste material placed as near to the staked lines and grades as skillful operation of the equipment will permit. Where the pond is constructed by a dragline, other types of equipment may be required to shape or spread the waste material. Bulldozers and graders are commonly used for this purpose.

Excavated ponds should be protected against erosion damage by a good cover of sod-forming grasses on the side slopes of the pond above the normal water level, the berms, the waste banks, and the emergency spillway, where required.

PART IV - SEALING PONDS AND RESERVOIRS

1. SEALING METHODS

GENERAL

Excessive seepage losses in farm ponds usually are due to the selection of a site where the soils are too permeable to hold water. This may be the result of inadequate site investigations in the planning stage. However, the need for water may be so important as to justify the selection of a permeable site. In such cases, plans for reducing seepage losses by sealing should be part of the design.

The problem of reducing seepage losses is one of reducing the permeability of the soils to a point where the losses become tolerable. Losses may be reduced by the methods discussed below, the choice of which will depend largely on the proportions of coarse grained sand and gravel and fine grained silt and clay in the soil. A thorough investigation of the materials to be sealed should be made by a soils scientist before the method of sealing is selected. In some cases it may be necessary to have a laboratory analysis of the materials.

SEALING BY COMPACTION ALONE

Pond areas containing a high percentage of coarse grained material can be made relatively impervious by compaction alone if the material is well graded from small gravel or coarse sand to fine sand, clay, and silt. This method of sealing is the least expensive of those presented in this chapter, but its use is limited to the soil conditions described.

The pond area should be cleared of all trees and other vegetation and all stump holes, crevices, and similar areas should be filled with relatively impervious material. The soil should be scarified to a depth of 8 to 10 inches with a disk, roto-tiller, pulverizer or similar equipment and all rocks and tree roots should be removed. The loosened soil should be rolled under optimum moisture conditions to a dense, tight layer with four to six passes of a sheepsfoot roller.

The thickness of the compacted seal should not be less than 8 inches for impoundments up to 10 feet in depth. Since seepage losses vary directly with the depth of water impounded, the thickness of the compacted seal should be increased proportionately when the depth of water exceeds 10 feet. This will require compacting the soil in two or more layers not exceeding 8 inches in thickness over that portion of the pond where the water depth exceeds 10 feet. In these cases the top layer or layers of soil will have to be removed and stockpiled while the bottom layer is being compacted.

USE OF CLAY BLANKETS

Pond areas containing high percentages of coarse grained soils but lacking sufficient amounts of clay to prevent high seepage losses can be

sealed by blanketing. The blanket should cover the entire area over which water is to be impounded. It should consist of material containing a wide range of particle sizes varying from small gravel or coarse sand to fine sand and clay in the desired proportions. Such material should contain approximately 20 percent by weight of clay particles.

The thickness of the blanket will depend on the depth of water to be impounded. The minimum thickness should be 12 inches for all depths of water up to 10 feet. The minimum should be increased by 2 inches for each foot of water over 10 feet. The construction procedure is similar to that described previously for constructing earth embankments.

Clay blankets require protection from cracking that results from drying or freezing and thawing. A cover of gravel, 12 to 18 inches thick, placed over the blanket may be used for this purpose. Blanketed areas should be protected by a cantilevered pipe or rock riprap where flow into the pond is concentrated.

SEALING WITH BENTONITE

Seepage losses in well graded coarse grained soils may be reduced by the addition of Bentonite. Bentonite is a fine textured colloidal clay that will absorb several times its own weight in water. At complete saturation it will swell from 8 to 15 times its original volume. When Bentonite is mixed in the correct proportions with the coarse grained material, and the mixture is thoroughly compacted and saturated, the particles of Bentonite will fill the pores in the material and make it nearly impervious. A laboratory analysis of the material is essential to determine the amount of Bentonite that should be applied per unit of area. Rates of application range from 1 to 3 pounds per square foot, depending on site conditions. Bentonite, upon drying, will return to its original volume and leave cracks in the pond area. For this reason, Bentonite is not recommended for ponds where a wide fluctuation in the water level is expected.

As with other methods, the pond area should be cleared of all vegetation and all holes, crevices and areas of exposed gravel should be filled or covered with suitable compacted material.

The soil moisture level in the area to be treated should be optimum for good compaction. If the area is found to be too wet, sealing operations should be postponed until moisture conditions are satisfactory. If the material is too dry, water should be added by sprinkling.

The Bentonite should be spread uniformly over the area to be treated at the rate determined by the laboratory analysis. The Bentonite is then thoroughly mixed with the soil to a depth of at least six inches with a roto-tiller, disk, or similar equipment. The area should then be compacted with four to six passes of a sheepsfoot roller.

Since considerable time may elapse between application of the Bentonite and the filling of the pond it may be necessary to protect the treated area by mulching with straw or hay anchored to the surface by the final passes of the sheepsfoot roller. Treated areas subject to inflow should be protected by riprap or other mechanical means.

TREATMENT WITH CHEMICAL ADDITIVES

Excessive seepage losses often occur in fine grained clay soils because of the arrangement of the clay particles which form a honeycomb structure. Such soils are said to be aggregated and have a relatively high permeability rate. The application of small amounts of certain chemicals to these aggregates may result in collapse of the open structure and rearrangement of the clay particles. The chemicals used are called dispersing agents.

For chemical treatment to be effective, the soils in the pond area should contain more than 50 percent of fine grained material (silt and clay finer than .074 mm diameter) and at least 15 percent of clay finer than .002 mm diameter. The soils should contain less than 0.5 percent soluble salts (based on dry soil weight). Chemical treatment is not effective in coarse grained soils.

While there are many soluble salts that meet the requirement of a dispersing agent, sodium polyphosphates are most commonly used. Tetrasodium Pyrophosphate (TSPP) and Sodium Tripolyphosphate (STPP) are most effective. These dispersants should be finely granular with 95 percent passing a No. 30 sieve and less than 5 percent passing a No. 100 sieve. They usually are applied at a rate of from 0.05 to 0.10 pounds per square foot. Sodium chloride, which is less effective, is applied at a rate of from 0.20 to 0.33 pounds per square foot. A laboratory analysis of the soils in the pond area is essential to determine which of these dispersing agents will be most effective and the rate at which it should be applied.

The dispersing agent is mixed with the surface soil and compacted to form a blanket. For depths of water up to 8 feet, the blanket thickness should be at least 6 inches. For depths of water greater than 8 feet, the blanket should be 12 inches thick treated in two 6-inch lifts. A minimum thickness of 12 inches is recommended for all areas in the range of water surface fluctuation.

The area to be treated should be cleared of all vegetation and trash. Rock outcrops and other exposed areas of highly permeable material should be covered with from 2 to 3 feet of fine grained soil. This material should then be thoroughly compacted. In cavernous limestone areas, the success or failure of the seal may depend upon the thickness and compaction of this initial blanket.

The soil moisture level in the area to be treated should be near optimum for compaction down to a depth of 12 inches. If the soil is too wet treatment should be postponed. Polyphosphates release water from the soil and the job could easily become too wet to handle. If the soil is too dry, water should be added by sprinkling.

The dispersing agent should be applied uniformly over the pond area at a rate determined by the laboratory analysis. The dispersant may be applied with a seeder, drill, fertilizer spreader or by hand broadcasting.

The dispersing agent should be thoroughly mixed into each 6-inch layer with a disk, roto-tiller, pulverizer or similar equipment. Operating the mixing equipment in two directions will produce best results. Each chemically treated layer should be thoroughly compacted with 4 to 6 passes of a sheepsfoot roller.

The treated blanket should be protected from puncture by livestock trampling. Areas near the normal waterline should also be protected from erosion by covering with a 12- to 18-inch blanket of gravel or other suitable material. Areas where inflow into the pond is concentrated should be protected with riprap or other erosion resistant materials such as concrete or metal pipe.

Due to rapid technologic advancements, new chemical additives are being developed constantly. Some of these may prove useful in reducing seepage losses.

USE OF FLEXIBLE MEMBRANES

Another method of reducing excessive seepage losses is the use of flexible membranes of Polyethylene, vinyl and butyl rubber.

Thin films of these materials are structurally weak but, if kept intact, they are almost completely watertight. Polyethylene films are less expensive and have better aging properties than vinyl. Vinyl is more resistant to impact damage and is readily seamed and patched with a solvent cement. Polyethylene can be joined or patched only by heat sealing. Butyl rubber can be joined or patched with a special cement.

These thin films must be protected from mechanical damage if they are to be serviceable. All polyethylene and vinyl rubber membranes should have a cover of earth or earth and gravel not less than 6 inches thick. Butyl rubber membranes need to be covered only in areas subject to travel by livestock. In these areas, a minimum cover of 9 inches should be used over all types of membranes. The bottom 3 inches of cover should not be coarser than silty sand.

All membranes should be of a quality that meets or exceeds the minimum requirements shown in the State Standards and Specifications for Pond Sealing or Lining. The minimum normal thickness should equal or exceed the value shown below for the soil material being covered and the type of membrane used.

Soil Material Not Coaser than:	Polyethylene	Vinyl	Butyl Rubber
Sands, Clean or Silty	8 mil.	8 mil.	15 mil.
Gravels, Clean, Silty or Clayey	15 mil.	15 mil.	30 mil.

The area to be lined should be drained and allowed to dry until the surface is firm and will support the men and equipment that must travel over it during installation of the lining.

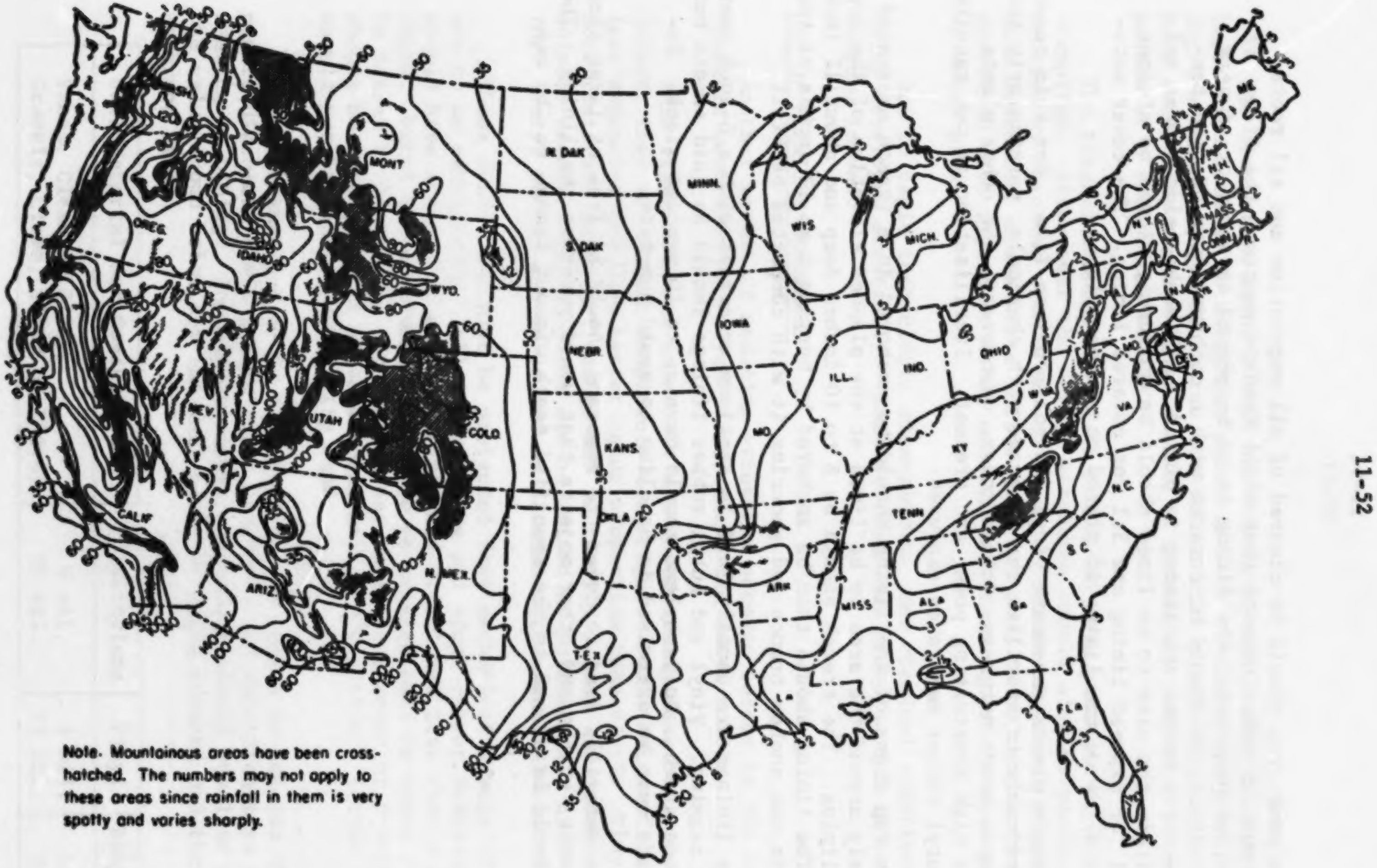
The pond area should be cleared of all vegetation and all roots, sharp stones or other objects that might tend to puncture the film. If the material over which the lining is to be placed is stony or of very coarse texture, it should be covered with a cushion layer of fine textured material before the lining is placed. All banks, side slopes and fills within the area to be lined should be uniformly sloped no steeper than 1:1 for exposed lining and 3:1 for covered lining. The cover material may slide on the lining if placed on steeper slopes.

Certain plants penetrate vinyl and polyethylene film. For this reason, it is desirable to sterilize the subgrade with chemicals, particularly the side slopes where nutgrass, Johnsongrass, quackgrass, and other plants having a high penetrating power are present. Sterilization is not required where butyl rubber membranes are used.

The top edges of the lining should be anchored in a trench excavated completely around the area to be lined at the planned elevation of the top of the lining. The trench should be 8 to 10 inches deep and about 12 inches wide. The lining should then be anchored by burying 8 to 12 inches of the lining in the anchor trench and securing it with compacted backfill.

The linings are usually laid in sections or strips with a 6-inch overlap for seaming. Vinyl and butyl rubber linings should be laid smooth but in a loose state. Polyethylene should have up to 10 percent slack. Extreme care must be exercised in handling to avoid puncture.

The materials used to cover the membrane should be free of large clods, sharp rocks, sticks and other objects that would puncture the lining. The cover should be placed to the specified depth without damage to the membrane.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GA.
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MISS.
TENN.
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OHIO
IND.
ILL.
MICH.
WIS.
MINN.
IOWA
MO.
ARK.
LA.
TEX.
OKLA.
KANS.
NEBR.
S.DAK.
N.DAK.
MONT.
WYO.
COLO.
N.MEX.
ARIZ.
UTAH
NEV.
IDAHO
OREG.
WASH.
CALIF.

Note. Mountainous areas have been cross-hatched. The numbers may not apply to these areas since rainfall in them is very spotty and varies sharply.

Exhibit 11–1 Guide for estimating approximate acres of drainage area required per acre-foot of storage in a farm pond.

Side slopes - 3 Horiz. to 1 Vert.

Discharge Q CFS	Slope Range		Bottom Width Feet	Stage Feet
	Minimum Percent	Maximum Percent		
15	3.3	12.2	8	.83
	3.5	18.2	12	.69
20	3.1	8.9	8	.97
	3.2	13.0	12	.81
	3.3	17.3	16	.70
25	2.9	7.1	8	1.09
	3.2	9.9	12	.91
	3.3	13.2	16	.79
	3.3	17.2	20	.70
30	2.9	6.0	8	1.20
	3.0	8.2	12	1.01
	3.0	10.7	16	.88
	3.3	13.8	20	.78
35	2.8	5.1	8	1.30
	2.9	6.9	12	1.10
	3.1	9.0	16	.94
	3.1	11.3	20	.85
	3.2	14.1	24	.77
40	2.7	4.5	8	1.40
	2.9	6.0	12	1.18
	2.9	7.6	16	1.03
	3.1	9.7	20	.91
	3.1	11.9	24	.83
45	2.6	4.1	8	1.49
	2.8	5.3	12	1.25
	2.9	6.7	16	1.09
	3.0	8.4	20	.98
	3.0	10.4	24	.89
50	2.7	3.7	8	1.57
	2.8	4.7	12	1.33
	2.8	6.0	16	1.16
	2.9	7.3	20	1.03
	3.1	9.0	24	.94
60	2.6	3.1	8	1.73
	2.7	3.9	12	1.47
	2.7	4.8	16	1.28
	2.9	5.9	20	1.15
	2.9	7.3	24	1.05
	3.0	8.6	28	.97
70	2.5	2.8	8	1.88
	2.6	3.3	12	1.60
	2.6	4.1	16	1.40
	2.7	5.0	20	1.26
	2.8	6.1	24	1.15
	2.9	7.0	28	1.05
80	2.5	2.9	12	1.72
	2.6	3.6	16	1.51
	2.7	4.3	20	1.35
	2.8	5.2	24	1.24
	2.8	5.9	28	1.14
	2.9	7.0	32	1.06
90	2.5	2.6	12	1.84
	2.5	3.1	16	1.61
	2.6	3.8	20	1.45
	2.7	4.5	24	1.32
	2.8	5.3	28	1.22
	2.8	6.1	32	1.14
100	2.5	2.8	16	1.71
	2.6	3.3	20	1.54
	2.6	4.0	24	1.41
	2.7	4.8	28	1.30
	2.7	5.3	32	1.21
	2.8	6.1	36	1.13
120	2.5	2.8	20	1.71
	2.6	3.2	24	1.56
	2.7	3.8	28	1.44
	2.7	4.2	32	1.34
	2.7	4.8	36	1.26
140	2.5	2.7	24	1.71
	2.5	3.2	28	1.58
	2.6	3.6	32	1.47
	2.6	4.0	36	1.38
	2.7	4.5	40	1.30
160	2.5	2.7	28	1.70
	2.5	3.1	32	1.58
	2.6	3.4	36	1.49
	2.6	3.8	40	1.40
	2.7	4.3	44	1.33
180	2.4	2.7	32	1.72
	2.4	3.0	36	1.60
	2.5	3.4	40	1.51
	2.6	3.7	44	1.43
200	2.5	2.7	36	1.70
	2.5	2.9	40	1.60
	2.5	3.3	44	1.52
	2.6	3.6	48	1.45
220	2.4	2.6	40	1.70
	2.5	2.9	44	1.61
	2.5	3.2	48	1.53
240	2.5	2.6	44	1.70
	2.5	2.9	48	1.62
	2.6	3.2	52	1.54
260	2.4	2.6	48	1.70
	2.5	2.9	52	1.62
280	2.4	2.6	52	1.70
300	2.5	2.6	56	1.69

Example of Use

Given: Discharge, Q=87 c.f.s. Spillway Slope, Exit section (from profile)= 4%.

Find: Bottom Width and Stage in Reservoir.

Procedure: Enter table from left at 90 c.f.s. Note that spillway slope (4%) falls within slope ranges corresponding to bottom widths of 24, 28, and 32 feet. Use narrower bottom width, 24 feet, to minimize meandering. Stage in Reservoir will be 1.32 feet.

Note: Computations based on: Roughness coefficient, n=.040.
Maximum velocity=5.50 ft. per sec.

Exhibit 11-2 Design table for vegetated spillways excavated in erosion resistant soils.

Side Slopes - 3 Horiz. to 1 Vert.

Discharge Q CFS	Slope Range		Bottom Width Feet	Stage Feet
	Minimum Percent	Maximum Percent		
10	3.5	4.7	8	.68
15	3.4	4.4	12	.69
	3.4	5.9	16	.60
20	3.3	3.3	12	.80
	3.3	4.1	16	.70
	3.5	5.3	20	.62
25	3.3	3.3	16	.79
	3.3	4.0	20	.70
	3.5	4.9	24	.64
30	3.3	3.3	20	.78
	3.3	4.0	24	.71
	3.4	4.7	28	.65
	3.4	5.5	32	.61
35	3.2	3.2	24	.77
	3.3	3.9	28	.71
	3.5	4.6	32	.66
	3.5	5.2	36	.62
40	3.3	3.3	28	.76
	3.4	3.8	32	.71
	3.4	4.4	36	.67
	3.4	5.0	40	.64
45	3.3	3.3	32	.76
	3.4	3.8	36	.71
	3.4	4.3	40	.67
	3.4	4.8	44	.64
50	3.3	3.3	36	.75
	3.3	3.8	40	.71
	3.3	4.3	44	.68
60	3.2	3.2	44	.75
	3.2	3.7	48	.72
70	3.3	3.3	52	.75
80	3.1	3.1	56	.78

Example of Use

Given: Discharge, Q=38 c.f.s. Spillway slope, exit section (from profile) =4%.

Find: Bottom Width and Stage in Reservoir.

Procedure: Enter table from left at 40 c.f.s. Note that spillway slope (4.0%) falls within slope ranges corresponding to bottom widths of 36 and 40 feet. Use narrower bottom width, 36 feet, to minimize meandering. Stage in Reservoir will be 0.67 feet.

Note: Computations based on: Roughness coefficient, n=.040
Maximum velocity=3.50 ft. per sec.

Exhibit 11-3 Design table for vegetated spillways excavated in very erodible soils.

Figure 1

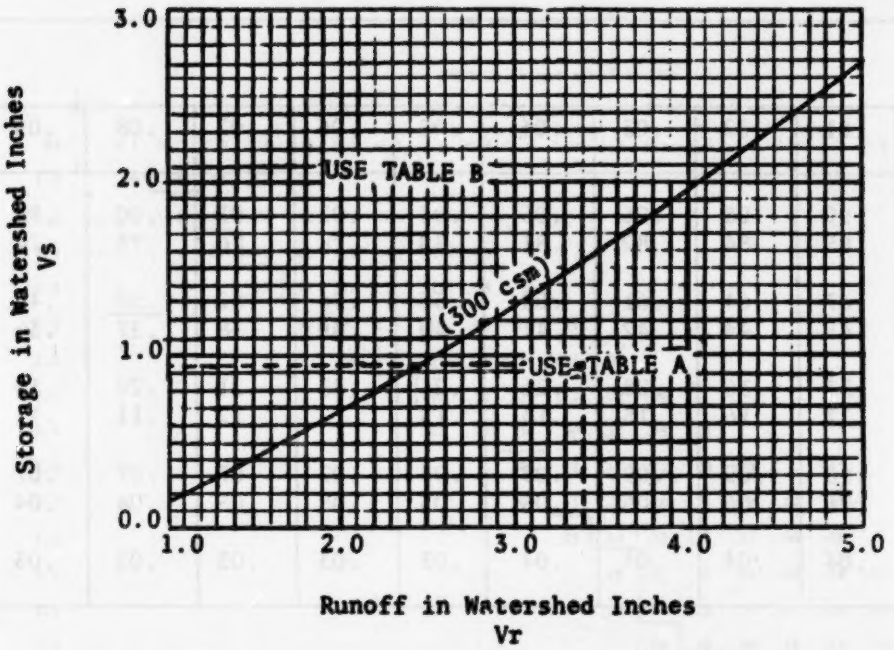

Figure 1 and Tables A and B can be used to determine the capacity of principal spillways considering temporary storage. Figure 1 is a plot of Vs versus Vr to determine which Table to use. Table A is for pipe flow structures with a discharge over 0.47 ft^3/s/acre (300 csm) and Table B is for pipe flow structures with a discharge under 0.47 ft^3/s/acre.

Description of Terms:

Vs = Volume of temporary storage, acre-feet or in.
Vr = Volume of runoff, acre-feet or in.
Qo = Required principal spillway discharge, ft^3/s (Table A) and ft^3/s/acre (Table B)
Qi = Peak flow from design storm, ft^3/s

Exhibit 11-4 Estimate of principal spillway discharge allowing for temporary storage.

Table A

$\frac{Vs}{Vr}$	0.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	1.00	.99	.98	.96	.95	.94	.92	.91	.90	.88
0.1	.87	.85	.84	.82	.81	.79	.78	.76	.75	.74
0.2	.70	.67	.64	.61	.58	.56	.54	.52	.50	.48
0.3	.47	.45	.44	.42	.41	.40	.39	.38	.37	.36
0.4	.35	.32	.30	.28	.26	.24	.23	.21	.20	.19
0.5	.18	.17	.16	.15	.14	.13	.12	.12	.11	.11
0.6	.10	.10	.09	.09	.08	.08	.07	.07	.07	.07
0.7	.06	.06	.06	.06	.05	.05	.05	.05	.04	.04
0.8	.04	.04	.04	.04	.04	.03	.03	.03	.03	.03

Table A: Values of Qo/Qi for pipe flow structures with a discharge over 0.47 ft^3/s/acre (300 csm).

Example #1:

Given:
Vs = 5.9 acre-feet or 0.94 in.
Vr = 21.1 acre-feet or 3.4 in.
Qi = 360 ft^3/s
D.A. = 75 acres

Find: Qo

Solution: Find the point for Vs of 0.94 in. and Vr of 3.4 in. in figure 1. Since the point is below the line, use Table A.

$$\frac{Vs}{Vr} = \frac{0.94}{3.4} = 0.28 \text{ (Vs and Vr must be in same units)}$$

$$\frac{Qo}{Qi} = 0.50 \text{ (From Table A)}$$

$$Qo = 0.50 \text{ X } Qi = 0.50 \text{ X } 360 \ ft^3/s = 180 \ ft^3/s$$

Exhibit 11-4 (cont.)

Table B

VALUES OF Qo IN ft³/s/acre

STORAGE IN WATERSHED INCHES

Vs

RUNOFF IN WATERSHED INCHES

Vr	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
1.0	.89	.39	.19	.10	.06																	
1.2		.62	.33	.20	.12	.08	.05	.04														
1.4			.57	.31	.21	.14	.09	.07	.05													
1.6				.57	.33	.23	.16	.11	.08	.06												
1.8					.59	.37	.25	.19	.13	.09	.06											
2.0						.64	.42	.27	.21	.14	.09	.06										
2.2							.62	.45	.32	.23	.13	.08	.05									
2.4								.65	.49	.34	.20	.12	.08	.05								
2.6										.49	.28	.17	.11	.08	.05							
2.8										.69	.41	.25	.16	.11	.08	.05						
3.0											.55	.34	.22	.15	.11	.08	.05					
3.2												.49	.31	.20	.14	.10	.08	.05				
3.4												.66	.44	.28	.19	.14	.10	.08	.05			
3.6													.56	.39	.26	.19	.14	.10	.08	.05		
3.8														.49	.34	.23	.16	.13	.10	.08	.05	
4.0														.65	.45	.31	.22	.17	.13	.09	.07	.05
4.2															.55	.41	.28	.20	.16	.12	.09	.07
4.4																.49	.36	.25	.21	.14	.12	.09
4.6																.62	.45	.33	.27	.19	.15	.12
4.8																	.55	.43	.33	.23	.19	.14
5.0																		.49	.39	.31	.23	.18

DISCHARGE VALUES TO THE LEFT OF LINE ARE TO BE USED FOR INTERPOLATION ONLY.

HOWEVER, INTERPOLATED VALUES SHOULD NOT EXCEED .47 ft³/s/acre

Table B is for pipe flow structures with a discharge under 0.47 ft³/s/acre (300 csm).

Example #2:

Given: Vs = 34 acre-feet or 1.6 in.
Vr = 3.2 in.
Qi = 420 ft³/s
D.A. = 256 acres (drainage area)

Find: Qo

Solution: Use Table B (determined from Figure 1)
Qo = 0.31 ft³/s/acre (from Table B)
= 0.31 ft³/s/acre X 256 acres = 79 ft³/s

Exhibit 11-4 (cont.)

DISCHARGE THROUGH NATURAL VEGETATED SPILLWAYS[1] - 2:1 END SLOPE (Z_1)

V_c	d_c	m	SLOPE OF NATURAL GROUND Z_2																							*Corr.Fact. Sideslope Change
			0.25	0.45	0.65	0.85	1.05	1.25	1.45	1.65	1.85	2.05	2.25	2.45	2.65	2.85	3.05	3.25	3.45	3.65	3.85	4.05	4.25	4.45	4.65	4.85	5.05	
1.134	0.08	.1	1.83	0.92	0.61	0.47	0.37	0.31	0.27	0.23	0.21	0.19	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.00
1.604	0.16	.2	10.30	5.17	3.46	2.64	2.09	1.75	1.51	1.32	1.18	1.07	0.97	0.90	0.83	0.77	0.72	0.68	0.64	0.61	0.58	0.55	0.53	0.51	0.49	0.47	0.45	0.02
1.964	0.24	.3	28.40	14.25	9.54	7.28	5.77	4.83	4.15	3.65	3.26	2.94	2.68	2.47	2.29	2.13	2.00	1.88	1.78	1.68	1.60	1.53	1.46	1.40	1.34	1.29	1.24	0.06
2.268	0.32	.4	58.30	29.26	19.59	14.95	11.85	9.91	8.53	7.49	6.68	6.04	5.51	5.07	4.70	4.38	4.10	3.86	3.65	3.46	3.29	3.14	3.00	2.87	2.76	2.65	2.56	0.12
2.535	0.40	.5	101.86	51.12	34.22	26.12	20.70	17.31	14.90	13.09	11.68	10.55	9.63	8.86	8.21	7.65	7.17	6.75	6.37	6.04	5.74	5.48	5.24	5.02	4.82	4.63	4.46	0.20
2.778	0.48	.6	160.60	80.64	53.98	41.21	32.65	27.31	23.50	20.64	18.42	16.64	15.19	13.98	12.95	12.07	11.30	10.64	10.05	9.53	9.06	8.64	8.26	7.91	7.60	7.31	7.04	0.32
3.001	0.56	.7	236.21	118.54	79.36	60.58	47.99	40.15	34.55	30.33	27.08	24.47	22.33	20.55	19.04	17.75	16.62	15.64	14.78	14.01	13.32	12.70	12.14	11.63	11.17	10.74	10.35	0.47
3.208	0.64	.8	329.77	165.89	110.80	84.57	67.00	56.06	48.24	42.37	37.81	34.16	31.17	28.68	26.58	24.78	23.21	21.84	20.64	19.56	18.60	17.74	16.95	16.24	15.59	15.00	14.45	0.66
3.402	0.72	.9	442.71	222.16	148.74	113.54	89.95	75.25	64.75	56.88	50.76	45.86	41.85	38.51	35.68	33.26	31.16	29.32	27.70	26.26	24.96	23.81	22.76	21.81	20.93	20.13	19.40	0.88
3.586	0.80	1.0	576.12	289.12	193.56	147.75	117.06	97.93	84.27	74.02	66.05	59.68	54.46	50.11	46.44	43.28	40.55	38.16	36.05	34.17	32.50	30.99	29.62	28.38	27.24	26.20	25.25	1.15
3.761	0.88	1.1		366.92	245.65	187.51	148.56	124.29	106.95	93.94	83.83	75.74	69.12	63.60	58.93	54.93	51.46	48.43	45.75	43.37	41.24	39.32	37.59	36.01	34.58	33.25	32.04	1.46
3.928	0.96	1.2		456.06	305.33	233.06	184.65	154.48	132.93	116.76	104.19	94.14	85.91	79.05	73.25	68.27	63.96	60.19	56.86	53.91	51.26	48.88	46.72	44.76	42.97	41.33	39.83	1.81
4.089	1.04	1.3		557.10	372.90	284.70	225.56	188.71	162.38	142.64	127.28	114.99	104.94	96.55	89.48	83.40	78.14	73.53	69.46	65.85	62.62	59.71	57.07	54.68	52.50	50.48	48.65	2.21
4.243	1.12	1.4			448.89	342.65	271.48	227.12	195.43	171.67	153.18	138.40	126.30	116.22	107.69	100.38	94.04	88.49	83.60	79.25	75.36	71.86	68.69	65.81	63.18	60.76	58.55	2.66
4.392	1.20	1.5			533.40	407.16	322.58	269.88	232.22	203.99	182.02	164.45	150.08	138.10	127.96	119.27	111.74	105.15	99.34	94.17	89.55	85.39	81.62	78.20	75.08	72.20	69.58	3.16
4.536	1.28	1.6			626.00	478.45	379.07	317.13	272.88	239.70	213.90	193.25	176.36	162.28	150.37	140.16	131.31	123.57	116.74	110.66	105.23	100.34	95.92	91.89	88.22	84.84	81.76	3.72
4.676	1.36	1.7				556.75	441.10	369.02	317.54	278.93	248.90	224.87	205.22	188.83	174.98	163.09	152.80	143.79	135.84	128.77	122.45	116.76	111.61	106.99	102.66	98.72	95.14	4.32
4.811	1.44	1.8				642.27	508.85	425.71	366.31	321.77	287.13	259.41	236.74	217.84	201.85	188.15	176.27	165.87	156.70	148.55	141.26	134.70	128.76	123.36	118.43	113.89	109.75	4.99
4.943	1.52	1.9					582.60	487.32	419.33	368.34	328.68	296.96	271.00	249.37	231.06	215.38	201.78	189.88	179.38	170.05	161.70	154.19	147.39	141.21	135.57	130.37	125.63	5.71
5.072	1.60	2.0					662.21	554.01	476.72	418.75	373.67	337.60	308.09	283.49	262.69	244.85	229.39	215.86	203.93	193.32	183.84	175.29	167.56	160.53	154.12	148.24	142.83	6.49
5.198	1.68	2.1						625.80	538.46	473.01	422.08	381.38	348.01	320.23	296.73	276.58	259.11	243.84	230.36	218.37	207.66	198.01	189.27	181.34	174.09	167.42	161.33	7.33
5.320	1.76	2.2							604.95	531.39	474.18	428.40	390.96	359.75	333.34	310.71	291.10	273.93	258.79	245.32	233.28	222.44	212.63	203.71	195.57	188.08	181.24	8.42
5.439	1.84	2.3								593.85	529.91	478.76	436.92	402.03	372.53	347.23	325.31	306.13	289.21	274.16	260.70	248.59	237.62	227.66	218.56	210.19	202.55	9.21
5.556	1.92	2.4									589.41	532.52	485.98	447.18	414.36	386.22	361.84	340.50	321.68	304.94	289.98	276.50	264.30	253.22	243.10	233.79	225.29	10.24
5.671	2.00	2.5										589.77	538.22	495.25	458.90	427.74	400.74	377.11	356.26	337.72	321.15	306.23	292.72	280.44	269.24	258.92	249.51	11.34

DISCHARGE THROUGH NATURAL VEGETATED SPILLWAYS[1] - 3:1 END SLOPE (Z_1)

V_c	d_c	m	SLOPE OF NATURAL GROUND Z_2																							*Corr.Fact. Sideslope Change
			0.25	0.45	0.65	0.85	1.05	1.25	1.45	1.65	1.85	2.05	2.25	2.45	2.65	2.85	3.05	3.25	3.45	3.65	3.85	4.05	4.25	4.45	4.65	4.85	5.05	
1.134	0.08	0.1	1.83	0.92	0.61	0.47	0.37	0.31	0.27	0.23	0.21	0.19	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.08	0.08	0.00
1.604	0.16	0.2	10.32	5.19	3.48	2.66	2.11	1.77	1.53	1.34	1.20	1.09	0.99	0.92	0.85	0.79	0.74	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.51	0.49	0.47	0.02
1.964	0.24	0.3	28.46	14.31	9.60	7.34	5.83	4.89	4.21	3.71	3.32	3.00	2.74	2.53	2.35	2.19	2.06	1.94	1.84	1.74	1.64	1.59	1.52	1.46	1.40	1.35	1.30	0.06
2.268	0.32	0.4	58.42	29.38	19.71	15.07	11.97	10.03	8.65	7.61	6.80	6.16	5.63	5.19	4.82	4.50	4.22	3.98	3.77	3.58	3.41	3.26	3.12	2.99	2.88	2.77	2.68	0.12
2.535	0.40	0.5	102.06	51.32	34.42	26.32	20.92	17.51	15.10	13.29	11.88	10.75	9.83	9.06	8.41	7.85	7.37	6.95	6.57	6.24	5.94	5.68	5.44	5.22	5.02	4.83	4.66	0.20
2.778	0.48	0.6	161.00	80.96	54.30	41.53	32.97	27.63	23.82	20.96	18.74	16.96	15.51	14.30	13.27	12.39	11.62	10.96	10.37	9.85	9.38	8.96	8.58	8.23	7.63	7.63	7.92	0.32
3.001	0.56	0.7	236.68	119.01	79.83	61.05	48.46	40.62	35.02	30.82	27.55	24.94	22.80	21.02	19.51	18.22	17.09	16.11	15.25	14.48	13.79	13.17	12.61	12.10	11.64	11.21	10.82	0.47
3.208	0.64	0.8	330.43	166.15	111.46	85.23	67.66	56.72	48.90	43.09	38.47	34.82	31.83	29.34	27.24	25.44	23.87	22.50	21.30	20.22	19.26	18.40	17.61	16.90	16.25	15.66	15.11	0.66
3.402	0.72	0.9	443.59	223.04	149.62	114.42	90.83	76.13	65.63	57.76	51.64	46.74	42.73	39.39	36.56	34.14	32.04	30.20	28.58	27.14	25.84	24.69	23.64	22.69	21.81	21.01	20.28	0.88
3.586	0.80	1.0	577.27	290.27	194.71	148.90	118.21	99.08	85.42	75.17	67.20	60.83	55.61	51.26	47.59	44.43	41.70	39.31	37.20	35.32	33.65	32.14	30.77	29.53	28.39	27.35	26.40	1.15
3.761	0.88	1.1		368.38	247.11	188.97	150.02	125.75	108.41	95.40	85.29	77.20	70.58	65.06	60.39	56.39	52.92	49.89	47.21	44.83	42.70	40.78	39.05	37.47	36.04	34.71	33.50	1.46
3.928	0.96	1.2		457.87	307.14	234.87	186.46	156.29	134.74	118.57	106.00	95.96	87.72	80.86	75.06	70.08	65.77	62.00	58.67	55.72	53.07	50.69	48.53	46.57	44.78	43.14	41.64	1.81
4.089	1.04	1.3		559.31	375.19	286.91	227.77	190.92	164.59	144.85	129.49	117.20	107.15	98.76	91.69	85.61	80.35	75.74	71.67	68.06	64.83	61.92	59.28	56.89	54.71	52.69	50.86	2.21
4.243	1.12	1.4			451.55	345.31	274.14	229.78	198.09	174.33	155.84	141.06	128.96	118.88	110.35	103.04	96.70	91.15	86.26	81.91	78.02	74.52	71.35	68.47	65.84	63.42	61.21	2.66
4.392	1.20	1.5			536.56	410.32	323.78	273.04	235.38	207.15	185.18	167.61	153.24	141.26	131.12	122.43	114.90	108.31	102.50	97.33	92.71	88.55	84.78	81.36	78.24	75.36	72.74	3.16
4.536	1.28	1.6			630.52	482.17	382.79	320.85	276.60	243.42	217.62	196.97	180.08	166.00	154.09	143.88	135.03	127.29	120.46	114.38	108.95	104.06	99.64	95.61	91.94	88.56	85.48	3.72
4.676	1.36	1.7				561.07	445.42	373.32	321.86	283.25	253.22	229.19	209.54	193.15	179.30	167.41	157.12	148.11	140.16	133.09	126.77	121.08	115.93	111.25	106.98	103.04	99.46	4.32
4.811	1.44	1.8				647.26	513.88	430.70	371.30	326.76	292.12	264.40	241.73	222.83	206.84	193.14	181.26	170.86	161.69	153.54	146.25	139.69	133.75	128.35	123.42	118.88	114.74	4.99
4.943	1.52	1.9					588.21	493.03	425.04	374.05	334.39	302.67	276.71	255.08	236.77	221.09	207.49	195.59	185.09	175.76	167.41	159.90	153.10	146.92	141.28	136.08	131.34	5.71
5.072	1.60	2.0					668.70	560.50	483.21	425.24	380.16	344.09	314.58	290.98	269.09	251.34	235.88	222.35	210.42	199.81	190.33	181.78	174.05	167.02	160.61	154.73	149.32	6.49
5.198	1.68	2.1						633.13	545.81	480.34	429.41	388.67	355.34	327.56	304.06	283.91	266.44	251.17	237.69	225.70	214.99	205.34	196.60	188.67	181.42	174.75	168.66	7.33
5.320	1.76	2.2							613.19	539.63	482.42	436.64	399.20	367.99	341.58	319.13	299.52	282.35	267.21	253.74	241.70	230.86	221.05	212.13	203.99	196.50	189.66	8.24
5.439	1.84	2.3								603.06	539.12	487.97	446.13	411.28	381.74	356.44	334.52	315.34	298.42	283.37	269.91	257.80	246.83	236.87	227.77	219.40	211.76	9.21
5.556	1.92	2.4									599.65	542.76	496.22	457.42	424.60	396.46	372.08	350.74	331.92	315.10	300.22	286.70	274.54	263.46	253.34	244.03	235.53	10.26
5.671	2.00	2.5										601.11	549.56	506.59	470.24	439.08	412.08	388.45	367.60	349.06	332.89	317.57	304.06	291.78	280.58	270.26	260.85	11.34

[1] applicable only where conditions for critical flow exist.

Exhibit 11-5 Discharge through natural vegetated spillways.

Fill Height	SIDE SLOPES					CROWN WIDTHS				
	2½:1 2½:1	2½:1 3:1	3:1 3:1	3½:1 3½:1	4:1 4:1	8	10	12	14	16
	2:1 3:1	2:1 3½:1	2½:1 3½:1	3:1 4:1	3:1 5:1					
1.0	3	3	3	4	4	8	10	12	14	16
1.2	4	4	4	5	6	10	12	14	17	19
1.4	5	5	6	7	8	11	14	17	20	22
1.6	6	7	8	9	10	13	16	19	22	26
1.8	8	9	10	11	13	14	18	22	25	29
2.0	10	11	12	14	16	16	20	24	28	32
2.2	12	13	15	17	19	18	22	27	31	35
2.4	14	16	17	20	23	19	24	29	34	39
2.6	17	19	20	24	27	21	26	31	36	42
2.8	20	22	23	27	31	22	28	34	39	45
3.0	22	25	27	32	36	24	30	36	42	48
3.2	26	28	31	36	41	26	32	38	45	51
3.4	29	32	35	40	46	27	34	41	47	55
3.6	32	36	39	45	52	29	36	43	50	58
3.8	36	40	43	50	58	30	38	46	53	61
4.0	40	44	48	56	64	32	40	48	56	64
4.2	44	49	53	62	71	34	42	50	59	67
4.4	48	53	58	68	77	35	44	53	61	71
4.6	53	58	63	74	85	37	46	55	64	74
4.8	57	63	69	81	92	38	48	57	67	77
5.0	62	69	75	87	100	40	50	60	70	80
5.2	67	74	81	94	108	42	52	62	73	83
5.4	73	80	87	102	117	43	54	65	75	87
5.6	78	86	94	110	125	45	56	67	78	90
5.8	84	93	101	118	135	46	58	69	81	93
6.0	90	99	108	126	144	48	60	72	84	96
6.2	96	106	115	135	154	50	62	74	87	99
6.4	102	113	123	143	164	51	64	77	89	103
6.6	109	120	131	152	174	53	66	79	92	106
6.8	116	128	139	162	185	54	68	81	95	109
7.0	123	135	147	172	196	56	70	84	98	112
7.2	130	143	156	182	207	58	72	86	101	115
7.4	138	152	165	193	219	59	74	89	103	119
7.6	145	159	174	203	231	61	76	91	106	122
7.8	153	168	183	214	243	62	78	93	109	125
8.0	160	176	192	224	256	64	80	96	112	128
8.2	169	185	202	235	269	66	82	98	115	131
8.4	177	194	212	247	282	67	84	101	117	135
8.6	186	204	222	259	296	69	86	103	120	138
8.8	194	213	232	271	310	70	88	105	123	141
9.0	203	223	243	283	324	72	90	108	126	144
9.2	212	233	254	296	339	74	92	110	129	147
9.4	222	244	266	310	353	75	94	113	131	151
9.6	231	254	277	323	369	77	96	115	134	154
9.8	241	265	289	337	384	78	98	117	137	157
10.0	250	275	300	350	400	80	100	120	140	160
10.2	260	286	313	364	416		102	122	143	163
10.4	271	298	325	379	433		104	125	145	167
10.6	281	309	338	394	449		106	127	148	170
10.8	292	321	350	409	467		108	129	151	173
11.0	302	333	363	424	484		110	132	154	176
11.2	313	344	376	440	502		112	134	157	179
11.4	325	357	390	456	520		114	137	159	183
11.6	336	370	404	472	538		116	139	162	186
11.8	348	383	418	488	557		118	141	165	189
12.0	360	396	432	504	576		120	144	168	192

Exhibit 11–6 End area table for embankment sections for various side slopes and crown widths.

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(Sheet 1 of 3)

Fill Height	SIDE SLOPES					CROWN WIDTHS				
	2½:1 2½:1 2:1 3:1	2½:1 3:1 2:1 3½:1	3:1 3:1 2½:1 3½:1	3½:1 3½:1 3:1 4:1	4:1 4:1 3:1 5:1	8	10	12	14	16
12.2	372	409	447	522	595		122	146	171	195
12.4	385	424	462	539	615		124	149	173	199
12.6	397	437	477	557	635		126	151	176	202
12.8	410	451	492	574	655		128	153	179	205
13.0	422	465	507	592	676		130	156	182	208
13.2	436	479	523	610	697		132	158	185	211
13.4	449	494	539	629	718		134	161	187	215
13.6	463	509	555	648	740		136	163	190	218
13.8	476	523	571	667	762		138	166	193	221
14.0	490	539	588	686	784		140	168	196	224
14.2	505	555	605	706	807		142	170	199	227
14.4	519	570	622	726	829		144	173	202	230
14.6	534	586	639	746	853		146	175	204	234
14.8	548	602	657	767	876		148	178	207	237
15.0	563	619	675	788	900		150	180	210	240
15.2	578	635	693	809	924		152	182	213	243
15.4	594	653	711	830	949		154	185	216	246
15.6	609	669	730	852	973		156	187	218	250
15.8	625	687	749	874	999		158	190	221	253
16.0	640	704	768	896	1024		160	192	224	256
16.2	656	722	787	919	1050			194	227	259
16.4	673	740	807	942	1076			197	230	262
16.6	689	758	827	965	1102			199	232	266
16.8	706	776	847	988	1129			202	235	269
17.0	723	795	867	1012	1156			204	238	272
17.2	740	814	888	1036	1183			206	241	275
17.4	757	833	909	1060	1211			209	244	278
17.6	774	852	930	1084	1239			211	246	282
17.8	792	871	951	1109	1267			214	249	285
18.0	810	891	972	1134	1296			216	252	288
18.2	828	911	994	1160	1325			218	255	291
18.4	846	931	1016	1186	1354			221	258	294
18.6	865	951	1038	1212	1384			223	260	298
18.8	884	972	1060	1238	1414			226	263	301
19.0	903	993	1083	1264	1444			228	266	304
19.2	922	1014	1106	1291	1475			230	269	307
19.4	941	1035	1129	1318	1505			233	272	310
19.6	960	1056	1152	1345	1537			235	274	314
19.8	980	1078	1176	1372	1568			238	277	317
20.0	1000	1100	1200	1400	1600			240	280	320
20.2	1020	1122	1224	1428	1632			242	283	323
20.4	1040	1144	1248	1457	1665			245	286	326
20.6	1061	1167	1273	1486	1697			247	288	330
20.8	1082	1190	1298	1515	1731			250	291	333
21.0	1103	1213	1323	1544	1764			252	294	336
21.2	1124	1236	1348	1574	1798			254	297	339
21.4	1145	1254	1374	1604	1832			257	300	342
21.6	1166	1283	1400	1634	1866			259	302	346
21.8	1188	1307	1426	1664	1901			262	305	349
22.0	1210	1331	1452	1694	1936			264	308	352
22.2	1232	1356	1479	1725	1971			266	311	355
22.4	1254	1380	1506	1756	2007			269	314	358
22.6	1277	1405	1533	1788	2043			271	316	362
22.8	1300	1430	1560	1820	2079			274	319	365
23.0	1323	1455	1587	1852	2116			276	322	368

Exhibit 11–6 **End area table for embankment sections for various side slopes and crown widths**

FILL HEIGHT	SIDE SLOPES					CROWN WIDTHS		
	2½:1 2½:1	2½:1 3:1	3:1 3:1	3½:1 3½:1	4:1 4:1	12	14	16
	2:1 3:1	2:1 3½:1	2½:1 3½:1	3:1 4:1	3:1 5:1			
23.2	1346	1480	1615	1884	2153	278	325	371
23.4	1369	1506	1643	1916	2190	281	328	374
23.6	1392	1532	1671	1949	2228	283	330	378
23.8	1416	1558	1699	1983	2266	286	333	381
24.0	1440	1584	1728	2016	2304	288	336	384
24.2	1464	1611	1757	2050	2343	290	339	387
24.4	1488	1637	1786	2084	2381	293	342	390
24.6	1513	1664	1815	2118	2421	295	344	394
24.8	1538	1691	1545	2153	2460	298	347	397
25.0	1563	1719	1875	2188	2500	300	350	400
25.2	1588	1746	1905	2223	2540	302	353	403
25.4	1613	1774	1935	2258	2581	305	356	406
25.6	1638	1802	1966	2294	2621	307	358	410
25.8	1664	1831	1997	2330	2663	310	361	413
26.0	1690	1859	2028	2366	2704	312	364	416
26.2	1716	1888	2059	2403	2746	314	367	419
26.4	1742	1917	2091	2439	2788	317	370	422
26.6	1769	1946	2123	2476	2830	319	372	426
26.8	1796	1975	2155	2514	2873	322	375	429
27.0	1823	2005	2187	2552	2916	324	378	432
27.2	1850	2035	2220	2589	2959	326	381	435
27.4	1877	2065	2252	2628	3003	329	384	438
27.6	1904	2095	2285	2666	3047	331	386	442
27.8	1932	2125	2319	2705	3091	334	389	445
28.0	1960	2156	2352	2744	3136	336	392	448
28.2	1988	2187	2386	2783	3181	338	395	491
28.4	2016	2218	2420	2823	3226	341	398	454
28.6	2045	2249	2454	2863	3272	343	400	458
28.8	2074	2281	2488	2903	3318	346	403	461
29.0	2103	2313	2523	2944	3364	348	406	464
29.2	2132	2345	2558	2984	3411	350	409	467
29.4	2161	2377	2593	3025	3457	353	412	470
29.6	2190	2409	2628	3067	3505	355	414	474
29.8	2220	2442	2664	3108	3552	358	417	477
30.0	2250	2475	2700	3150	3600	360	420	480

NOTE: TO FIND THE END AREA FOR ANY FILL HEIGHT ADD SQUARE FEET FOUND UNDER STAKED SIDE SLOPES TO THAT UNDER THE CROWN WIDTH USED FOR TOTAL FOR SECTION. EXAMPLE: 6.4 FILL. 3:1 FRONT AND BACK SLOPES 14' CROWN WIDTH: 123+ 89= 212 SQUARE FEET TOTAL FOR SECTION. ANY COMBINATION OF SLOPES THAT ADD TO 5, 6, OR 7 MAY BE USED. A COMBINATION OF 3½:1 FRONT AND 2½:1 BACK WILL GIVE THE SAME RESULTS AS 3:1 FRONT AND BACK.

Exhibit 11–6 **End area table for embankment sections for various side slopes and crown widths**

Pond Inflow, Q c.f.s.	Pipe Diameter inches 1/	Pond Inflow, Q c.f.s.	Pipe Diameter inches 1/
0 - 6	15	30 - 46	36
6 - 9	18	46 - 67	42
9 - 13	21	67 - 92	48
13 - 18	24	92 - 122	54
18 - 30	30	122 - 158	60

1/ Based on a free outlet and a minimum pipe slope of 1.0 percent with the water level 0.5 foot above the top of the pipe at its upstream end.

Exhibit 11-7 Diameters of pipe inlets required to discharge various rates of inflow into excavated ponds.

ENGINEERING FIELD MANUAL

CHAPTER 12. SPRINGS AND WELLS

Compiled by: Daniel H. Griswold, Engineering Geologist, SCS, Portland, Ore.

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ENGINEERING FIELD MANUAL

CHAPTER 12. SPRINGS AND WELLS

1. GENERAL

About one-fifth of all water used in the United States, except for power generation, is from underground sources. Ground water has numerous advantages and its economic importance can hardly be overemphasized. Springs and wells are man's principal sources.

DEFINITIONS

A spring is a natural outflow of water from the ground surface, usually from a definite opening. A seep is similar to a spring but differs in that it has no definite opening.

A water well is a vertical excavation of small diameter made for the purpose of obtaining water from the openings in the rocks or voids in the soil which it penetrates.

INTRODUCTION

This chapter provides general information on ground-water occurrence and methods of recovery.

Springs are classified according to geologic structure and the force bringing water to the surface. The characteristics of springs and methods of improving and developing them are described and illustrated. The production requirements, basis for site selection, and the various methods of constructing wells for domestic, livestock, and irrigation water supplies are discussed. The importance and methods of well design, development, testing and pump selection also are noted and discussed.

2. SOURCE OF SUPPLY

SUBSURFACE WATER

That portion of precipitation which soaks into the ground is called subsurface water. Subsurface water which moves down to the underground reservoir in the saturated zone is called ground water. The upper surface of this saturated zone is known as the water table.

Downward moving water may be trapped by lenses of impervious material preventing it from reaching the main water table. Hence, a secondary water table is formed which is said to be perched. Ground water moves horizontally and down gradient with the water table.

GROUND WATER

Ground water may be present in voids in soil and rock and in openings along faults, fractures, joints and solution passages in rock. The amount of water available from soil or unconsolidated materials depends more on the size, uniformity and continuity of the openings than upon the volume of voids. For example, uniform coarse sand or small gravel with 30 to 40 percent voids will yield many times the volume of water obtainable from clay having 45 to 55 percent voids.

Water-Bearing Materials

Unconsolidated sands or gravels generally are the most important aquifers (water-bearing strata). Usually, they have high porosity and permeability. Jointed and permeable sandstone and jointed limestone containing solution passages are next in importance as aquifers. The movement of water in sandstone is controlled by the uniformity, compaction and cementation of the sand and the frequency of joint openings. Ground water in limestone occurs in joints and solution passages.

The occurrence of ground water in volcanic rock depends on the presence of joints and fractures, or voids in cinders or alluvial deposits between lava flows.

Small amounts of ground water may be obtained in weathered, jointed, or fractured zones of dense, hard rock. The depth to which joints and fractures stand open in such rock usually is not more than 300 feet and may average about 90 feet. Little, if any, water may be obtained in unbroken areas of such rocks.

Clays and shale are practically impermeable. They do not yield water to wells in appreciable amounts, although occasionally water is obtained from shale that is strong enough to maintain open fractures. Clay or shale frequently confine water in more permeable materials.

Effect of Geologic Structure

Certain deep structural features or conditions favor accumulation of ground water in aquifers, while others may act as drains. Conditions that act to retain ground water are as necessary for underground storage as are dams for surface reservoirs. Such geologic dams, or traps, may be structural in nature or may be caused by the arrangement of the rock in strata or layers. Major geologic structures favoring accumulation and retention of ground water are synclines, grabens, faults and dikes. See sketched sections, Figure 12-1.

Minor structural features such as joints, fractures, and bedding also influence the occurrence and movement of ground water in rocks. Joints often occur in a definite pattern that may be useful in locating wells.

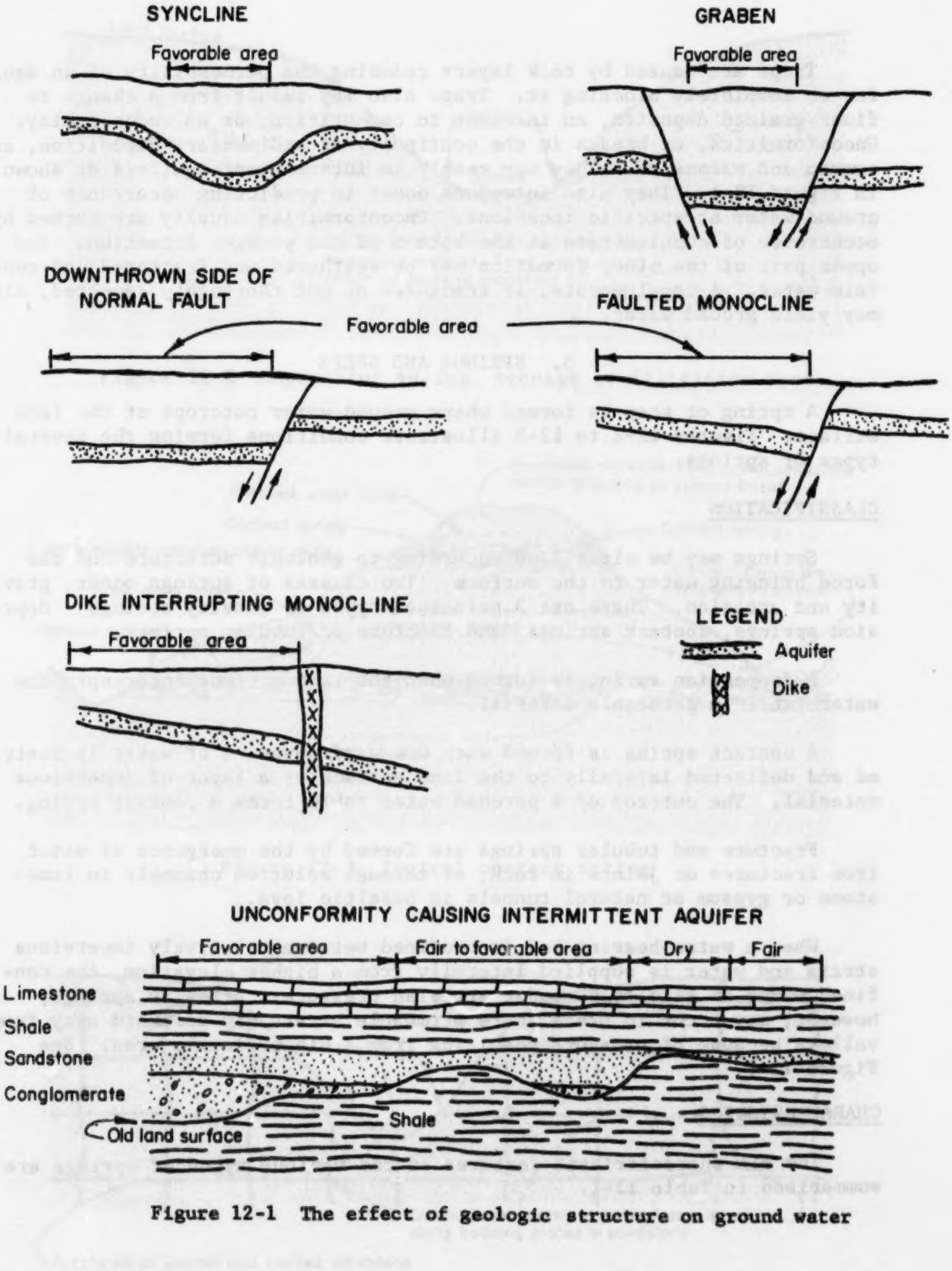

SYNCLINE
Favorable area
GRABEN
Favorable area
DOWNTHROWN SIDE OF NORMAL FAULT
FAULTED MONOCLINE
Favorable area
DIKE INTERRUPTING MONOCLINE
Favorable area
LEGEND
Aquifer
Dike
UNCONFORMITY CAUSING INTERMITTENT AQUIFER
Favorable area
Fair to favorable area
Dry
Fair
Limestone
Shale
Sandstone
Conglomerate
Old land surface
Shale

Figure 12-1 The effect of geologic structure on ground water

Traps are caused by rock layers reducing the permeability of an aquifer or completely blocking it. Traps also may result from a change to finer-grained deposits, an increase in cementation, or an unconformity. Unconformities, or breaks in the continuity of sedimentary deposition, are common and extensive. They may result in intermittent aquifers as shown in Figure 12-1. They also introduce doubt in predicting occurrence of ground water at specific locations. Unconformities usually are marked by occurrence of conglomerate at the bottom of the younger formation. The upper part of the older formation may be weathered and fractured and contain water. A conglomerate, if fractured or not thoroughly cemented, also may yield ground water.

3. SPRINGS AND SEEPS

A spring or seep is formed where ground water outcrops at the land surface. Figures 12-2 to 12-8 illustrate conditions forming the several types of springs.

CLASSIFICATION

Springs may be classified according to geologic structure and the force bringing water to the surface. Two classes of springs occur, gravity and artesian. There are 3 principal types of gravity springs: depression springs, contact springs, and fracture or tubular springs.

A depression spring is formed when the land surface intercepts the water table in permeable material.

A contact spring is formed when downward movement of water is restricted and deflected laterally to the land surface by a layer of impervious material. The outcrop of a perched water table forms a contact spring.

Fracture and tubular springs are formed by the emergence of water from fractures or joints in rock, or through solution channels in limestone or gypsum or natural tunnels in basaltic lava.

When a water-bearing bed is confined between relatively impervious strata and water is supplied laterally from a higher elevation, the confined water is said to be under artesian pressure. Artesian springs, however, may occur in areas where permeable strata dip downward away from valleys because of pressure resulting from a higher intake area. See Figure 12-7.

CHARACTERISTICS

The six characteristic features of the various types of springs are summarized in Table 12-1.

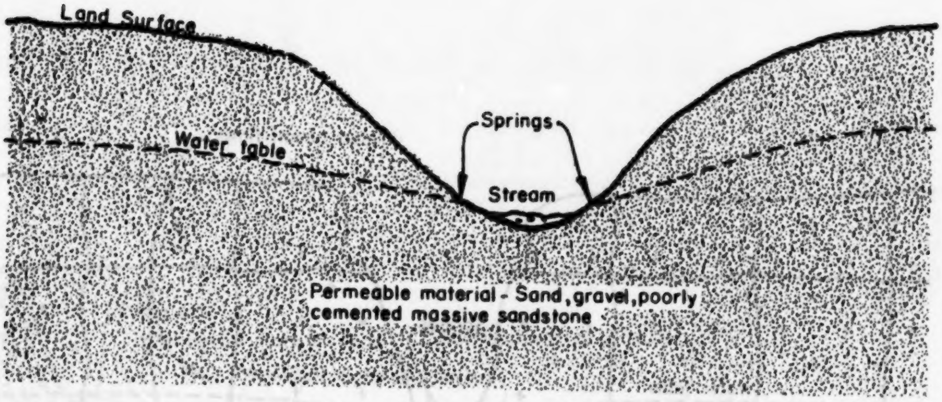

Land Surface
Springs
Water table
Stream
Permeable material - Sand, gravel, poorly cemented massive sandstone

Figure 12-2 Depression spring, seepage or filtration type

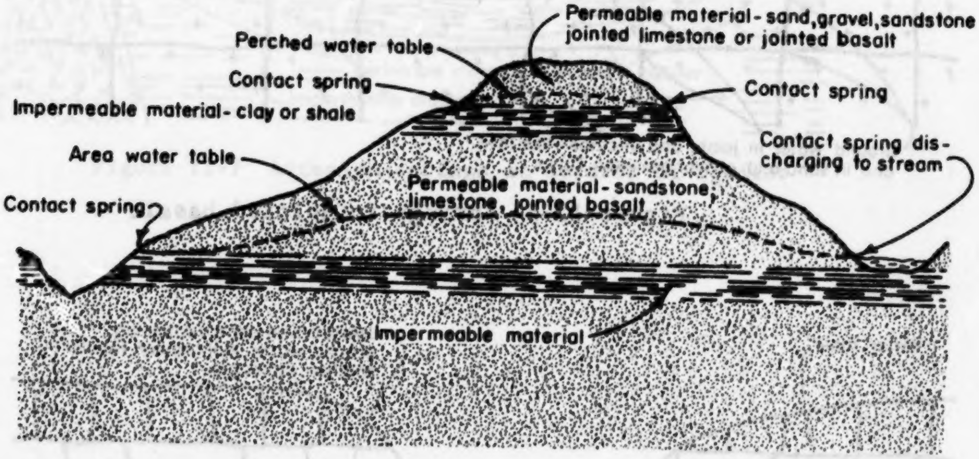

Permeable material - sand, gravel, sandstone jointed limestone or jointed basalt
Perched water table
Contact spring
Contact spring
Impermeable material - clay or shale
Contact spring discharging to stream
Area water table
Permeable material - sandstone, limestone, jointed basalt
Contact spring
Impermeable material

Figure 12-3 Typical contact spring

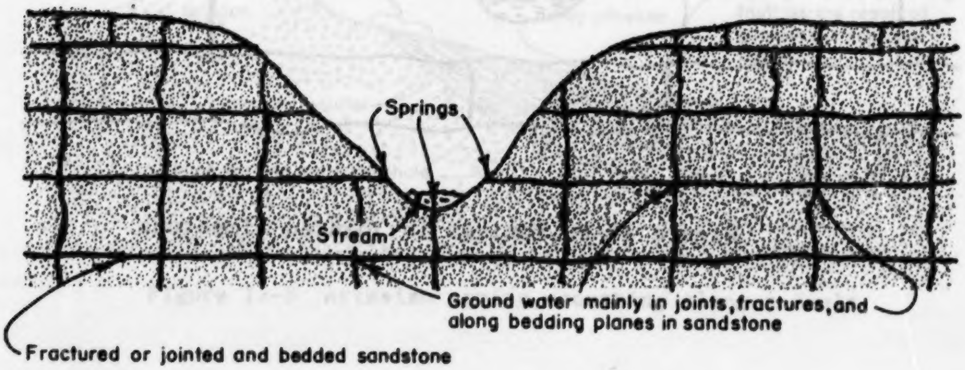

Springs
Stream
Ground water mainly in joints, fractures, and along bedding planes in sandstone
Fractured or jointed and bedded sandstone

Figure 12-4 Spring in jointed sandstone

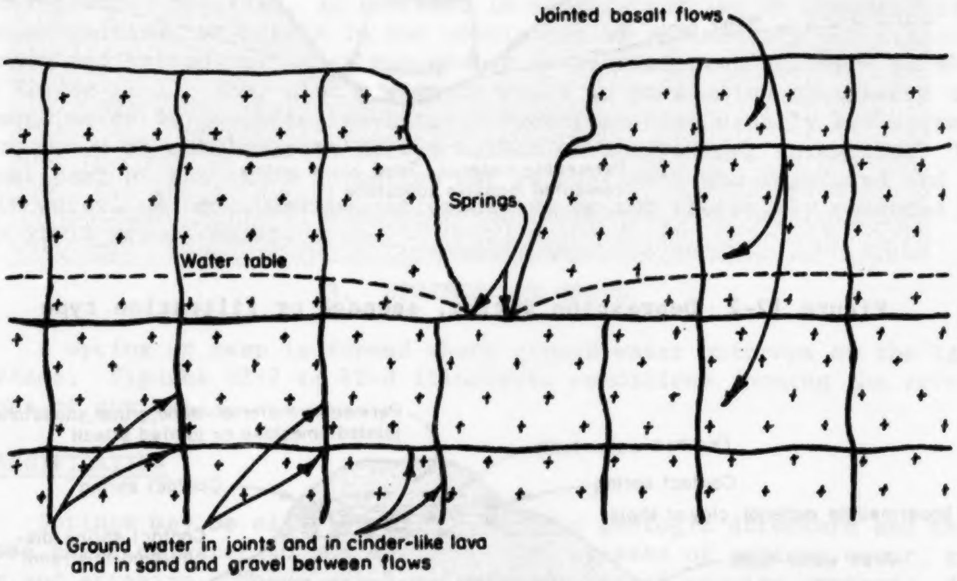

Jointed basalt flows
Springs
Water table
Ground water in joints and in cinder-like lava and in sand and gravel between flows

Figure 12-5 Springs in jointed basalt

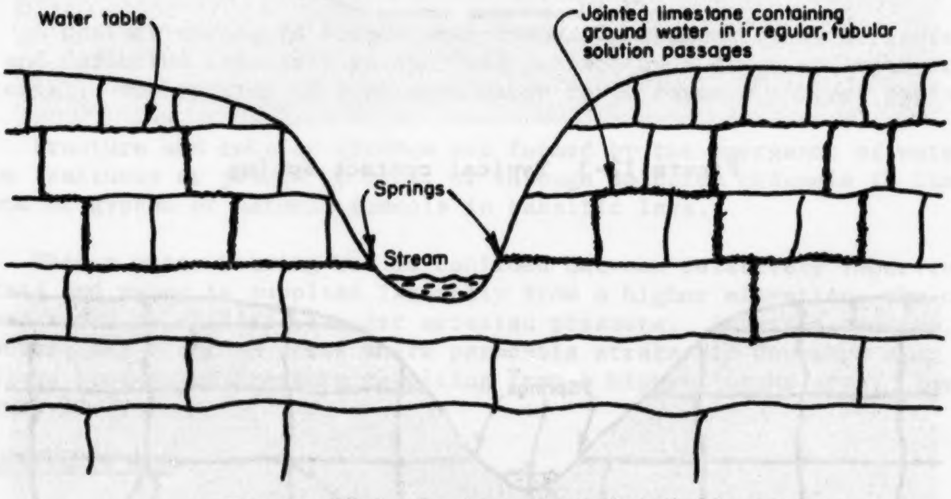

Water table
Jointed limestone containing ground water in irregular, tubular solution passages
Springs
Stream

Figure 12-6 Springs in jointed limestone

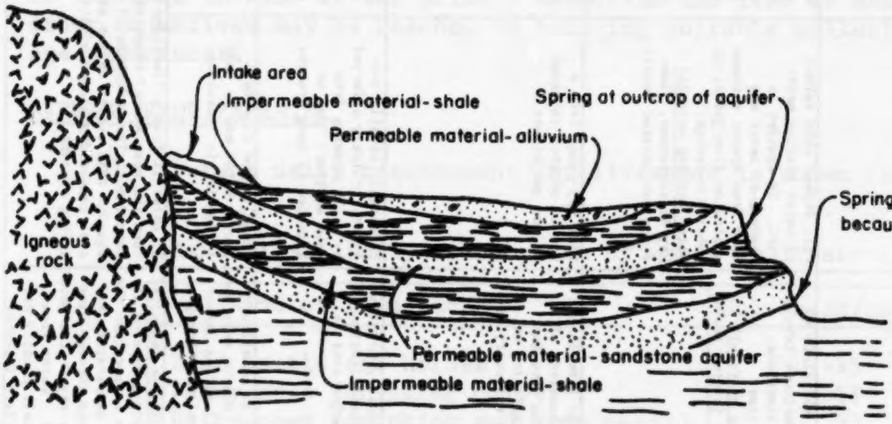

Intake area
Impermeable material-shale
Spring at outcrop of aquifer
Permeable material-alluvium
Springs weak or absent because of limited intake
Igneous rock
Permeable material-sandstone aquifer
Impermeable material-shale

Figure 12-7 Artesian springs at outcrop of aquifer

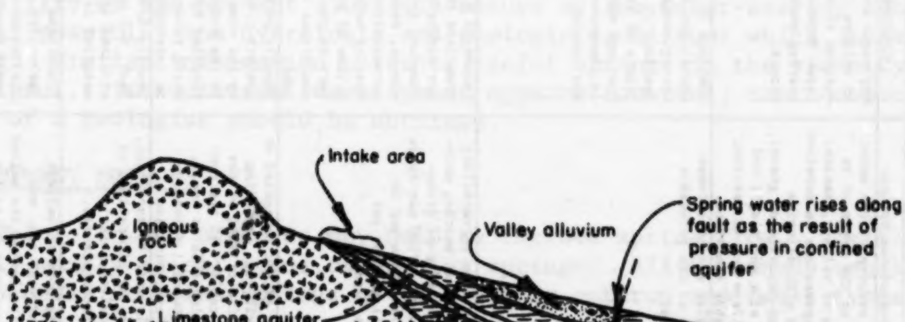

Intake area
Igneous rock
Valley alluvium
Spring water rises along fault as the result of pressure in confined aquifer
Limestone aquifer
Impermeable material-shale
Fault
Impermeable material-shale

Figure 12-8 Artesian spring occurring along a fault

Table 12-1 Characteristic features of springs

Type of Spring / Characteristic	GRAVITY			ARTESIAN	
	Depression Springs	Contact Springs	Fracture and Tubular Springs	Aquifer Outcrop Springs	Fault Springs
Location	Along outcrop of the water table at the edges or in bottom of valleys, basins, and depressions in moraines filled with alluvium (stream deposits of gravel, sand, silt and clay); and in valleys cut in massive, permeable sandstone.	May occur on hillsides or in valleys wherever the outcrop of an impermeable layer beneath a water bearing permeable layer occurs.	On hillsides or in valleys or wherever land surface is below the water table.	May occur in any topographic position along outcrop of aquifer.	May occur at any location along a fault or related fractures.
Type of Opening and Water Bearing Material	Irregular spaces between grains of the permeable material.	Openings in sand or gravel are irregular, intergranular spaces. Openings in rocks are joints or fractures. Openings may be tubular in limestone, gypsum, and basalt.	Fractures in all kinds of rocks and sometimes tubular openings in limestone, gypsum, and lava. Water bearing material - Fractured or jointed rocks.	Will depend upon nature of water bearing material. If aquifer is sandstone, water may seep from spaces between grains or from joints or tubular openings. Water bearing material - May be sandstone, limestone, or jointed basalt.	Will depend upon the nature of materials at the land surface. If the surface is alluvium, water will issue from spaces between grains. If the surface is rock, water will issue from fractures. Water bearing material - May be sandstone, limestone, or basalt. Surface material may not indicate the nature of the aquifer.
Yield	Depends upon permeability of the water bearing material and size of tributary area. Flow may range from less than one to several gallons per minute (gpm).	Volume of flow may range from less than a gallon per minute to several thousand gallons per minute, depending upon permeability of the water bearing material, the volume of aquifer tributary to the spring, and conditions of water intake.	Flow may range from less than one to hundreds of gpm, depending upon the extent of fracturing or joint system tributary to the opening.	Flow may range from a few to several thousand gallon per minute.	Volume of flow may range from a few to several thousand gallon per minute.
Type of Flow	May be either perennial or intermittent, depending upon rise or fall of the water table. If the contributing area is small, the flow will depend on local precipitation.	Usually perennial for contact springs supplied by the area water table. If the contact spring is supplied by a perched water table, the flow may be intermittent.	Usually perennial, may fluctuate with precipitation if the contributing area is small.	Perennial, usually constant. Quickly affected by wells drawing from same aquifer. May be affected by long drouths.	Perennial, constant, and only affected by long periods of drouth. Quickly affected by pumping from wells drawing upon the source aquifer.
Quality of Water	Usually fair to excellent, but may be mineralized if the aquifer contains soluble substances.	Usually fair to excellent, but may be mineralized if water bearing material is soluble.	Usually good to excellent. May be hard, due to calcium carbonate, if spring issues from or percolates through limestone.	Usually good to excellent. Water may be hard if aquifer is limestone.	Usually good to excellent. Water may be hard if aquifer is limestone.
Features Produced	Usually none in valleys. In windswept arid and semiarid basins the wetted area and the vegetation growing around the spring may cause deposition of material resulting in a mound of loess and organic matter.	Travertine (calcium carbonate) will be deposited as described under Fracture and Tubular Springs.	Travertine will be deposited about the spring opening if the water is warmer than the mean annual temperature and has percolated through limestone on its way to the point of discharge. Water from other materials usually produces no surface features.	If water is from a limestone aquifer and is warmer than the mean annual temperature, travertine will be deposited. The reduction of pressure in an artesian aquifer that occurs as the water reaches the surface also causes deposition of dissolved solids about the spring opening.	

4. DEVELOPMENT OF SPRINGS AND SEEPS

OBJECTIVES

The usual objectives of spring development are increased flow, improved usability, and protection from contamination. In most instances an increase in flow is the primary need. If the flow is adequate, the other objectives may be reached by building suitable collection and storage structures.

AVERAGE REQUIREMENTS

The average daily requirement for livestock is shown in Table 12-2.

Table 12-2 Daily consumption of water by livestock

Kind of livestock	Gal./head/day
Beef cattle and horses	12-15
Dairy cows (drinking only)	15
Dairy cows (drinking and barn needs)	35
Hogs	4
Sheep	2

PRELIMINARY INVESTIGATION

A preliminary investigation should be made, preferably during a dry season, before developing a plan. Information needed is the volume and reliability of the present flow; the nature of the water-bearing material; and, if possible, the hydrologic and geologic conditions which cause the spring. Similar information on other useful springs in the vicinity will be helpful. If successful development appears doubtful, the recommendations of a geologist should be obtained.

DEVELOPMENT METHODS

The following measures may help to improve spring flow. The first 3 apply mainly to all types of gravity springs. All 4 methods usually will benefit artesian springs of the aquifer outcrop and fault types.

Removal of Obstructions

Obstructions to flow may be cemented deposits of travertine, loose fine-grained materials (sand, silt, or clay) brought to the outlet by spring flow, or slope wash materials deposited on the outlet by surface waters. Vegetation growing in or about the outlet may obstruct flow and will consume water which would otherwise issue as spring flow. Usually the removal of such materials or growths will increase the flow of springs.

If the spring water carries sediment to the opening, some means of desilting the water, such as a sump, is desirable. A sump should be located below the spring so that the sediment will not build up over the outlet between periodic cleanings. It normally is designed to be cleaned by sluicing.

Ditches located to divert surface runoff away from the spring will prevent the clogging of outlets by slope wash material. If the collection of several small flows is planned, covered galleries or drains may be used to avoid the need for cleaning and maintaining open ditches.

Collection of Flow

At some locations, collecting the flow from several openings, or seeping from an outcrop of water-bearing material, is the only means of development. Where water issues from fractures, the individual openings should be cleaned. The water is collected by means of a tile, perforated pipeline, or gravel-filled ditch graded to a central sump or spring box. In collecting water seeping from permeable material, the ditch or tunnel should expose the length and thickness of the water-bearing zones. The excavation should extend sufficiently below the water-bearing zones to fully intercept the flow and permit free flow into the collector. See Figure 12-9.

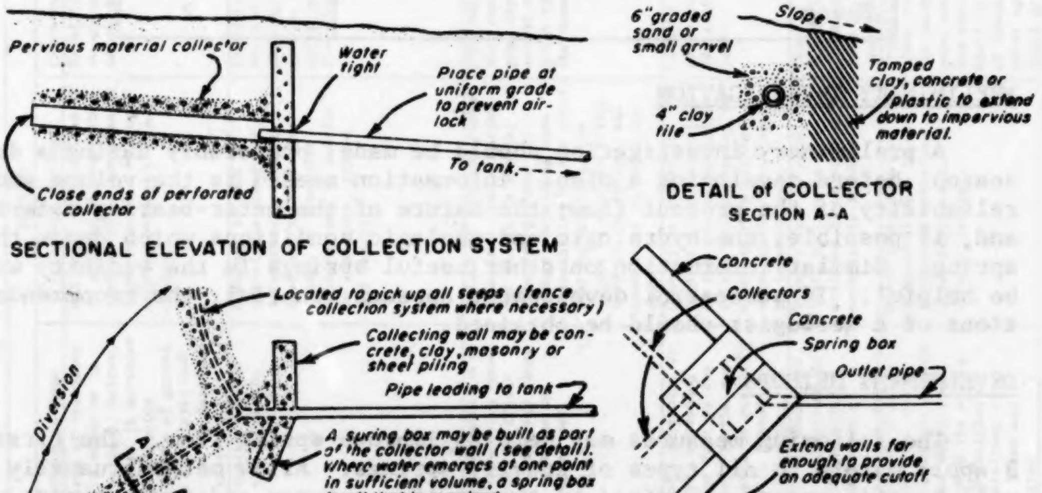

Pervious material collector
Water tight
Place pipe at uniform grade to prevent air-lock
To tank
Close ends of perforated collector
SECTIONAL ELEVATION OF COLLECTION SYSTEM
6" graded sand or small gravel
Slope
Tamped clay, concrete or plastic to extend down to impervious material.
4" clay tile
DETAIL of COLLECTOR SECTION A-A
Located to pick up all seeps (fence collection system where necessary)
Collecting wall may be concrete, clay, masonry or sheet piling
Pipe leading to tank
Diversion
A
A spring box may be built as part of the collector wall (see detail). Where water emerges at one point in sufficient volume, a spring box is all that is required
Collectors may be tile, perforated pipe or gravel
PLAN
Concrete
Collectors
Concrete
Spring box
Outlet pipe
Extend walls far enough to provide an adequate cutoff
PLAN of SPRING BOX USED WITH COLLECTION SYSTEM

Figure 12-9 Spring collection system

Drainage of Additional Area of the Water-Bearing Formation

The flow of seepage and contact-type springs usually can be increased by an excavation located to drain additional portions of the aquifer. Such excavations may be either ditches or tunnels, depending upon topography at the spring, the characteristics of the water-bearing materials, and the underlying materials.

Fracture and tubular springs may be improved by finding and cleaning out additional water-bearing fractures or passages.

If the spring occurs in gently sloping or nearly level land, a ditch along the outcrop of the water-bearing material usually will be the most economical method. The ditch should be located to drain the maximum area of the water-bearing zone.

A tunnel or infiltration gallery may be the most practical method of developing seepage springs or contact springs found on steep slopes. If the water-bearing material is consolidated, a tunnel in the underlying material exposing the bottom of the aquifer will stand open with a minimum of support. If both the water-bearing and the underlying material are unconsolidated, the tunnel should be dug in the bottom of the water-bearing materials on the contact with the underlying deposits. Similarly, if the water-bearing materials are unconsolidated and the underlying materials are consolidated, the tunnel should be dug in the former but on contact with the consolidated deposits. Tunneling in unconsolidated deposits will require support of the roof and lining to prevent cave-ins. Miners or others experienced in, and equipped for, such work should be employed for extensive tunneling. The guiding principle in excavating tunnels for water development is "follow the water."

Lowering Outlet Elevation

This method improves the flow of springs which are supplied by an extensive system of channels in rock, or by a large volume of permeable water-bearing material, as in some artesian springs. By lowering the outlet elevation, the added head of water increases the flow at the spring. If the volume of ground water contributing to the outlet is great, the lowering of the outlet will produce a long-lasting increase in flow. If the volume of water contributing to the spring is limited, the increase in flow may be of short duration. A study of the source of supply, therefore, should precede lowering the outlet.

Explosives

The shattering and dislocation of rock resulting from blasting may close fractures or joints and cause the existing flow to cease or to issue at some other location. Therefore, the use of explosives is not recommended in spring development.

STRUCTURES

The second and third objectives of spring development, improved usability and protection from contamination, usually require some means of collecting the flow and conveying it to the point of use. Various methods of collection may be used, including:

1. Tile or perforated pipeline laid in a gravel-filled ditch.
2. Drainage ditch backfilled with gravel or sand.
3. Infiltration galleries.
4. Tunnels.

Selection of the method should be based on conditions of spring occurrence, such as topography, nature of the water-bearing material, type of opening from which water issues, and volume of flow.

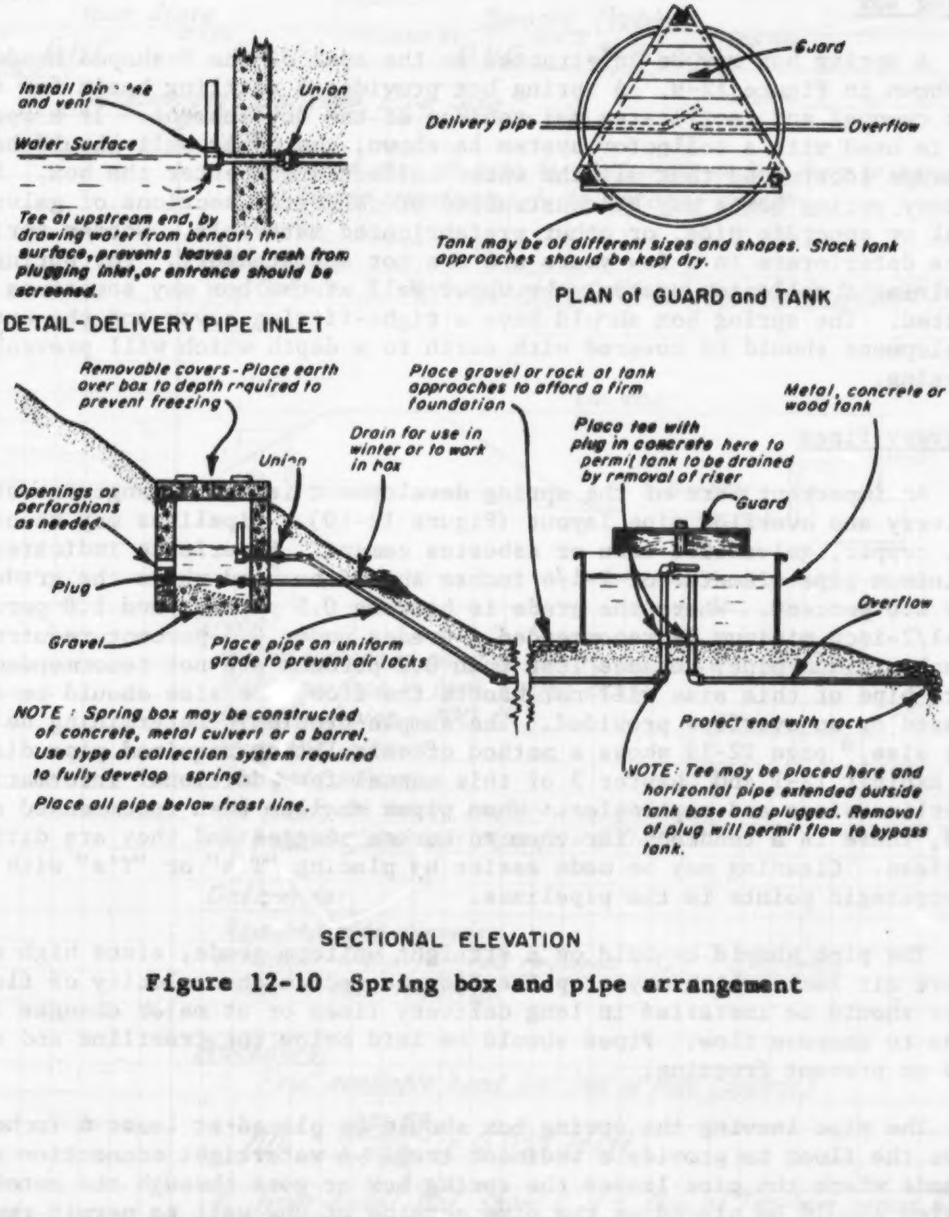
A spring box and pipeline are the most satisfactory means of delivering water to the point of use. The spring box or collecting basin should be designed and located so that water does not pond over the spring openings. Ponding above the spring openings will reduce spring flow and may cause seeps to change their path of flow.

Sketches of a typical spring collection system and a spring box and pipe arrangement are shown in Figures 12-9 and 12-10. The collection system shown is suitable for developing a seepage or filtration spring, Figure 12-2, and a contact spring, Figure 12-3.

Collector

The collector may consist of tile or perforated pipe laid in graded small gravel (1/4-inch or less in diameter) or graded sand, as shown in Figure 12-9; or it may be a ditch backfilled with graded small gravel or graded sand. In constructing a collector in permeable material, it is good practice to construct a cutoff wall of clay, concrete, or other impervious material in the downhill side of the trench. The cutoff should extend down to impervious material to intercept the water and cause it to flow to the point of collection. Under some conditions sand points may be driven into saturated material to serve as collectors.

In plan, the headwall or cutoff is usually constructed as a large V, with the apex downhill and the wingwalls extending into the hill to prevent water from escaping. If concrete is used, the wall should be at least 6-inches thick. Masonry, sheet piling, plastic, or clay may also be used for the headwall, which should extend deep enough to prevent underflow.


Install pipe tee and vent
Union
Water Surface
Guard
Delivery pipe
Overflow
Removable covers - Place earth over box to depth required to prevent freezing
Union
Openings or perforations as needed
Plug
Gravel
Drain for use in winter or to work in box
Place pipe on uniform grade to prevent air locks
Place gravel or rock at tank approaches to afford a firm foundation
Metal, concrete or wood tank
Place tee with plug in concrete here to permit tank to be drained by removal of riser
Guard
Overflow
Protect end with rock

Tee at upstream end, by drawing water from beneath the surface, prevents leaves or trash from plugging inlet, or entrance should be screened.

DETAIL-DELIVERY PIPE INLET

Tank may be of different sizes and shapes. Stock tank approaches should be kept dry.

PLAN of GUARD and TANK

NOTE : Spring box may be constructed of concrete, metal culvert or a barrel. Use type of collection system required to fully develop spring.

Place all pipe below frost line.

NOTE: Tee may be placed here and horizontal pipe extended outside tank base and plugged. Removal of plug will permit flow to bypass tank.

SECTIONAL ELEVATION

Figure 12-10 Spring box and pipe arrangement

Spring Box

A spring box may be constructed in the apex of the V-shaped headwall as shown in Figure 12-9. A spring box provides a settling basin for sediment removal and facilitates maintenance of the development. If a spring box is used with a collector system as shown, the upper wall should have openings located so that all the water collected can enter the box. Satisfactory spring boxes may be constructed of concrete, sections of galvanized metal or concrete pipe, or other prefabricated materials. Wooden spring boxes deteriorate in a few years and are not satisfactory. For springs not requiring a collector system, the upper wall of the box may sometimes be omitted. The spring box should have a tight-fitting cover and the entire development should be covered with earth to a depth which will prevent freezing.

Delivery Pipes

An important part of the spring development is the arrangement of the delivery and overflow pipe layout (Figure 12-10). Pipelines may be of plastic, copper, galvanized iron or asbestos cement. Experience indicates that a minimum pipe diameter of 1-1/4 inches should be used where the grade is over 1.0 percent. Where the grade is between 0.5 percent and 1.0 percent, a 1-1/2-inch minimum is recommended. Grades under 0.5 percent require a 2-inch minimum pipe. Grades less than 0.2 percent are not recommended. Where pipe of this size will not handle the flow, the size should be increased or an overflow provided. The sample problem, "Determining delivery pipe size," page 12-15 shows a method of calculating required pipe diameter. See Exhibit 12-1 and Chapter 3 of this manual for additional information on waterline sizes and capacities. When pipes smaller than recommended are used, there is a tendency for them to become clogged and they are difficult to clean. Cleaning may be made easier by placing "T's" or "Y's" with plugs at strategic points in the pipelines.

The pipe should be laid on a straight uniform grade, since high spots create air locks which may stop the flow or reduce the velocity of flow. Vents should be installed in long delivery lines or at major changes in grade to improve flow. Pipes should be laid below the frostline and covered to prevent freezing.

The pipe leaving the spring box should be placed at least 6 inches above the floor to provide a sediment trap. A watertight connection should be made where the pipe leaves the spring box or goes through the cutoff wall. A union should be placed on the pipe outside of the wall to permit removal for maintenance. A tee and vent pipe should be installed on the pipe within the spring box to reduce plugging from leaves or trash, or the entrance to the pipe should be screened.

The pipe connection with the water tank may be made in a number of ways. The practice of bringing the pipe under the tank and vertically through the bottom is the most desirable where the tank is to be used during freezing weather. It is good practice to have the inlet and outlet pipes fairly close together near the center of the tank. Even though the water may

COMPUTATION SHEET
SCS-523A REV 5-58

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

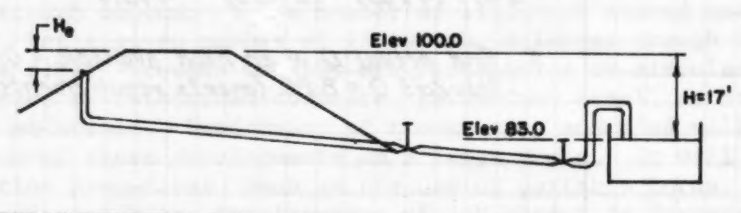
STATE Your State | PROJECT Sample Problem
BY R.F.F. | DATE 3-1-63 | CHECKED BY D.H.G. | DATE 2-15-68 | JOB NO.
SUBJECT Determining Delivery Pipe Size | SHEET 1 OF 2

Find:

Required size of pipe for delivering water from a pond or spring development to watering trough.

References:

Chapter 3, Hydraulics, and Exhibit 12-1, Sheets 1, 2, and 3.



Given:

Water surface in pond or spring box - Elev 100.0
Water surface in tank - Elev 83.0
Length of pipe - 490 ft
Four 90° elbows
Two gate valves
Minimum discharge required - 7 gal/min
Use galvanized iron pipe ($n = 0.017$)

Determine:

Required pipe diameter
Minimum entrance head required (H_e) = Entrance loss + velocity head

Procedure:

1. Find available head per foot of pipe (approx)

$$H/L = \frac{100-83}{490} = 0.035 \text{ ft/ft}$$

2. From Exhibit 12-1, Sheet 2 of 3, flow of 7 gal/min versus head loss of 0.035 ft/ft gives a pipe diameter between $1\frac{1}{4}$" and $1\frac{1}{2}$". Use $1\frac{1}{2}$" diameter pipe; then $Q = 9$ gal/min and velocity = 1.63 ft/sec.

3. Interpolate from chart I the minimum head required over the entrance when velocity = 1.63 ft/sec
$H_e = 0.08'$

Figure 12-11 Determining delivery pipe sizes (sheet 1)

COMPUTATION SHEET
SCS-523A REV 5-58

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

STATE Your State	PROJECT Sample problem		
BY R.F.F.	DATE 3-1-63	CHECKED BY D.H.G.	DATE 2-15-68	JOB NO.
SUBJECT Determining Delivery Pipe Size			SHEET 2 OF 2

4. Determine exact head available (ft/ft)

$$\frac{\text{Total head} - (\text{Entrance loss} + \text{velocity head})}{\text{Length of pipe} + \text{Equivalent length of fittings (Chart II)}}$$

$$\frac{17.0 - 0.08}{490 + (4 \times 0.7) + (2 \times 0.3)} = \frac{16.92}{493.4} = 0.034 \text{ ft/ft}$$

5. Find actual Q when head available = 0.034 ft/ft Exhibit 12-1 Shts 2 of 3 Q = 8.86 (meets requirements)

Figure 12-11 Determining delivery pipe sizes (sheet 2)

freeze around the edge of the tank, it will tend to stay open at the center. Figure 12-10 shows a good method of bringing the delivery pipe into the tank and of bypassing the flow.

Water Troughs

The water trough should be located where it is easy to get to by livestock, and well away from the spring box and collection system. It may be located to serve more than one field. The trough should be placed at a well-drained location or the site should be drained. In most instances, the area adjacent to the trough should be paved.

The size of trough depends on the number of livestock served and the volume of inflow. For a given number of livestock, a larger trough is needed for a small flow. Troughs usually are rectangular or circular, and should be constructed of reinforced concrete, galvanized steel, or other equally permanent materials. Uniformity of trough size and kind will help in the installation of these developments on a large scale. It will permit standard installation procedures, such as the use of portable forms, the assembly of standard pipe kits, the issuance of job sheets to farmers, bills of materials, and other operating procedures. The two sizes and shapes of concrete watering troughs shown in Figures 12-12 and 12-13 will fill the needs under most conditions.

RECTANGULAR CONCRETE TROUGH - CONSTRUCTION NOTES:

1. Capacity - 31 cubic feet or 232 gallons.
2. Concrete mix - 1 part cement, 2 parts sand, 3 parts gravel (by volume). Water - use 5 gallons of water per sack of cement for average damp sand (dry sand - use 5-1/2 gallons; wet - use 4-1/2 gallons).
3. Reinforcing steel - 3/8-inch diameter reinforcing bars placed in the center of all walls and floor slab, and spaced on 6-inch centers both ways; or 6 x 6-inch welded steel reinforcing fabric of #6- or #8-gage.
4. Side walls - 4-inch at top, battered to 6-inch at bottom.
5. Floor slab - should be placed 6 inches thick on 6-inch layer compacted gravel.
6. Concrete needed - 1-1/4 cubic yards (includes wastage allowance).

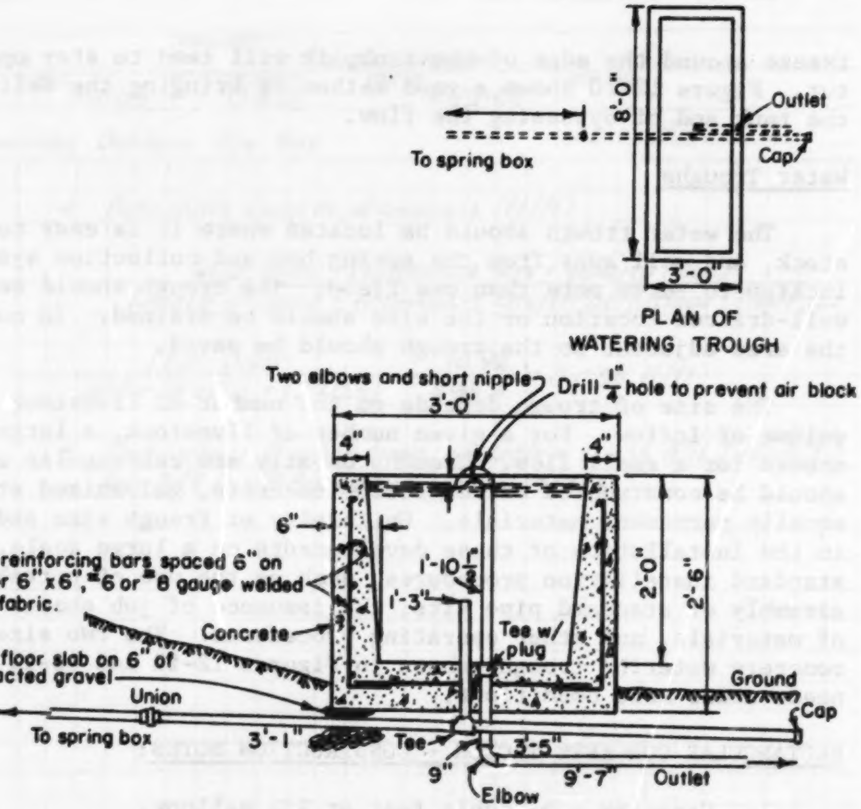

8'-0"
Outlet
Cap
To spring box
3'-0"
PLAN OF
WATERING TROUGH
Two elbows and short nipple
Drill 1/4" hole to prevent air block
3'-0"
4"
4"
6"
3/8" dia. reinforcing bars spaced 6" on ctrs. or 6" x 6", #6 or #8 gauge welded steel fabric.
1'-10 1/2"
2'-0"
2'-6"
1'-3"
Concrete
Tee w/ plug
Place floor slab on 6" of compacted gravel
Ground
Union
Cap
To spring box
3'-1"
Tee
3'-5"
9"
9'-7"
Outlet
Elbow

Figure 12-12 Details of rectangular trough

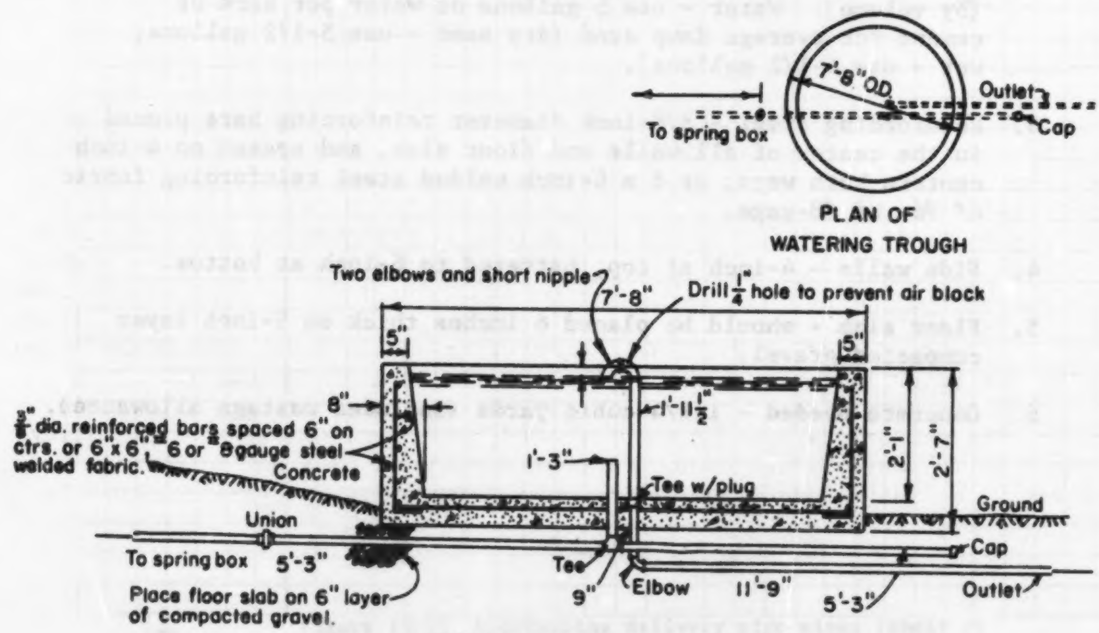

7'-8" O.D.
Outlet
To spring box
Cap
PLAN OF
WATERING TROUGH
Two elbows and short nipple
7'-8"
Drill 1/4" hole to prevent air block
5"
5"
8"
1'-1 1/2"
3/8" dia. reinforced bars spaced 6" on ctrs. or 6" x 6", #6 or #8 gauge steel welded fabric.
1'-3"
2'-1"
2'-7"
Concrete
Tee w/plug
Ground
Union
Cap
To spring box
5'-3"
Tee
Elbow
11'-9"
5'-3"
Outlet
9"
Place floor slab on 6" layer of compacted gravel.

Figure 12-13 Details of circular trough

CIRCULAR CONCRETE TROUGH - CONSTRUCTION NOTES:

1. Capacity - 71 cubic feet or 532 gallons.
2. Refer to paragraphs 2 and 3 under Rectangular Concrete Trough.
3. Side walls - 5-inch at top, battered to 8-inch at bottom.
4. Floor slab - should be placed 6 inches thick on 6-inch layer compacted gravel.
5. Concrete needed - 1-7/8 cubic yards (includes wastage allowance).

Protection

Springs often occur at locations subject to flooding. Protection should be afforded to the spring and its improvements to permit use without costly maintenance. Diversions properly located will afford protection in many instances. The spring itself may be developed so that floodflows passing over the top will not cause damage. The water trough should be set above frequent floodwater level. The collection system and box should be enclosed by a substantial fence to exclude livestock.

5. HYDRAULIC RAMS

DEFINITION

A hydraulic ram is a pump operated by water power. It uses the power developed by a given quantity of falling water to force a much lesser amount to an elevation above the source of supply.

OPERATION

Water is conducted to the ram through a drivepipe which operates under a head, depending on the difference in elevation between the source of supply and the ram. (See Figures 12-14 and 12-15.) The water entering the ram is under pressure and is allowed to escape through the outside valve until a certain velocity is reached. At this velocity, pressure causes the outside valve to close quickly and the inside check valve to open, forcing a small portion of the flow into the air chamber and out the delivery pipe. As soon as the pressures equalize, the check valve leading to the air chamber closes, the escape or outside valve opens and water again flows out the escape valve until the velocity is built up to close it, repeating the process. Each surge of the ram forces a certain amount of water out through the delivery pipe. The pulsations occur from 25 to 100 times a minute, so the resulting discharge is nearly continuous. Since the ram must have air to operate properly, and will not ordinarily operate under water, provision should be made to drain away the waste water.

DESIGN

The volume of water that a ram will pump depends on the fall between the source of supply and the ram, the height the water is to be raised from the ram to the outlet, and the quantity of water available.

The following data are needed to design a hydraulic ram installation (see Figure 12-15):

1. Fall in feet from the source of supply to the site of the ram.
2. Length of pipe required to conduct the water from the source of supply to the ram.
3. Height in feet the water is to be raised - vertical distance between ram and point of delivery.
4. Length of pipe required to conduct the water from the ram to the point of delivery.
5. Supply of water available to the ram in gallons per minute. The available flow should be measured during the dry season through use of a weir or by catching it in a container.
6. Volume of water output required in gallons per day.

Providing this information to ram manufacturers will enable them to make recommendations regarding the installation. Manufacturers build rams that will operate on flows of 1-1/2 gpm or more when operating under a fall of not less than 2.0 feet. The proposed size of ram and details of piping should be checked against the manufacturers' recommendations for the site conditions because of variations in design and operating characteristics.

The following formula gives the number of gallons that will be delivered per hour to a given point by a ram:

$$D = \frac{V \times F \times 40}{E}$$

D = gallons per hour that the ram will deliver
V = gallons per minute of supply water available
F = fall in feet to ram
E = vertical height in feet water is to be raised

Example:

V = 15 gpm
F = 5 feet
E = 60 feet

$$D = \frac{15 \times 5 \times 40}{60}$$

$$= 50 \text{ gallons per hour}$$

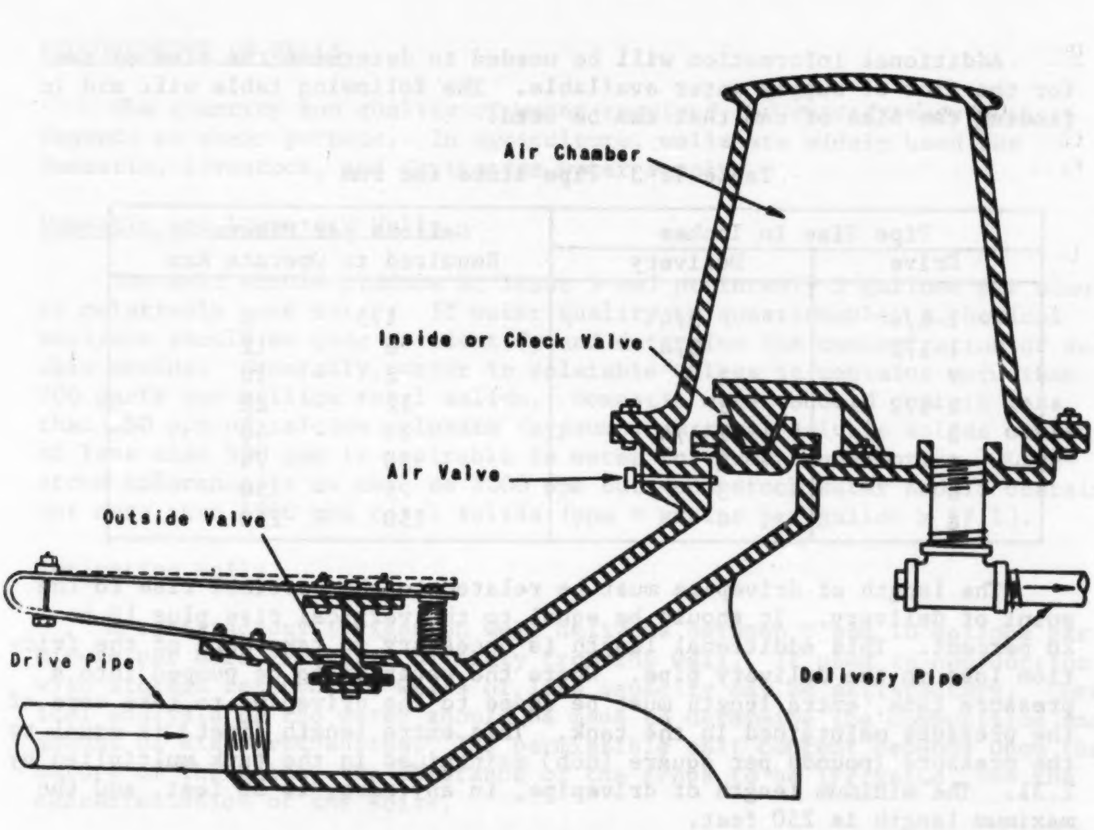

Air Chamber
Inside or Check Valve
Air Valve
Outside Valve
Drive Pipe
Delivery Pipe

Figure 12-14 Diagrammatic sketch of ram

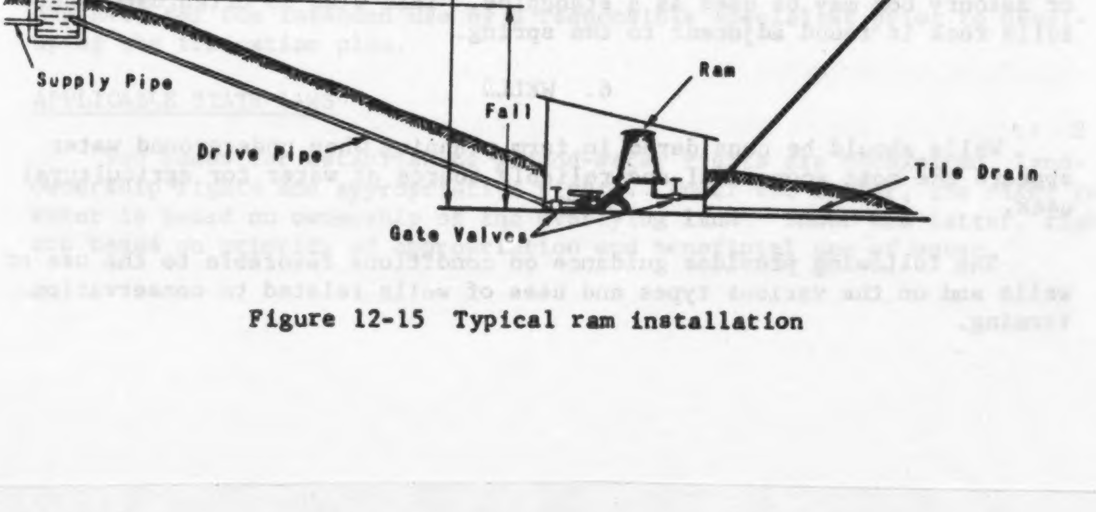

Reservoir
Delivery Pipe
Elevation
Supply Pipe
Ram
Fall
Drive Pipe
Tile Drain
Gate Valves

Figure 12-15 Typical ram installation

Additional information will be needed to determine the size of ram for the flow of supply water available. The following table will aid in finding the size of ram that can be used.

Table 12-3 Pipe sizes for ram

Pipe Size in Inches		Gallons per Minute Required to Operate Ram
Drive	Delivery	
1-1/4	3/4	1.5 - 6
1-1/2	3/4	6 - 12
2	1	8 - 18
2-1/2	1	12 - 28
3	1-1/4	20 - 40
4	2	30 - 75
6	3	75 - 150
8	4	150 - 250

The length of drivepipe must be related to the vertical rise to the point of delivery. It should be equal to the vertical rise plus 10 to 20 percent. This additional length is necessary to take care of the friction loss in the delivery pipe. Where the water is to be pumped into a pressure tank, extra length must be added to the drivepipe to take care of the pressure maintained in the tank. This extra length (feet) is equal to the pressure (pounds per square inch) maintained in the tank multiplied by 2.31. The minimum length of drivepipe, in any case, is 30 feet, and the maximum length is 250 feet.

Where the distance from the ram location to the spring is greater than the length of drivepipe required, a pipe one size larger than the drivepipe should be used to connect the drivepipe and supply pipe.

Where these two pipes join, use a "T" into which is fitted an open standpipe that is at least two sizes larger than the supply pipe. The top of the standpipe should be a few inches above the level of the water at the source of supply.

In cases where the supply pipe and drivepipe cannot be carried through on a straight incline, or where they come together at an angle, a concrete or masonry box may be used as a standpipe. This plan is often used where solid rock is found adjacent to the spring.

6. WELLS

Wells should be considered in farm planning when underground water appears the most economical and reliable source of water for agricultural uses.

The following provides guidance on conditions favorable to the use of wells and on the various types and uses of wells related to conservation farming.

REQUIREMENTS OF WELLS

The quantity and quality of water required for satisfactory wells depends on their purpose. In agriculture, wells are widely used for domestic, livestock, and irrigation water supply.

Domestic and Livestock Wells

The well should produce at least 3 and preferably 5 gallons per minute of relatively pure water. If water quality is questionable, a chemical analysis should be made to identify and determine the concentration of soluble solids. Generally, water is palatable unless it contains more than 700 parts per million total solids. Domestic water should contain less than 250 ppm of calcium sulphate (gypsum). A total soluble solids content of less than 500 ppm is desirable in water for human consumption. Livestock tolerance is as much as 2000 ppm but good stock water should contain not more than 1000 ppm total solids (ppm = grains per gallon x 17.1).

Irrigation Wells

A satisfactory irrigation well delivers between 5 and 10 gallons per minute per acre irrigated directly from the well. If used in conjunction with storage reservoirs, wells of less capacity may be satisfactory. Chemical analysis of the water should be made to determine the composition and amount of dissolved solids. The permissible salt content depends upon the nature of the salts, the tolerance of the crops to be irrigated, and the characteristics of the soils.

The quality of water for irrigation depends upon:

1. Total concentration of soluble salts.
2. Relative proportion of sodium to calcium or magnesium.
3. Concentration of boron or other elements that may be toxic.
4. Under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium.

Any questionable chemical analysis should be reviewed and the water approved for the intended use by a responsible specialist prior to developing the irrigation plan.

APPLICABLE STATE LAWS

Two bases for establishing ground-water rights are recognized, landownership rights and appropriative rights. Under the former, the right to water is based on ownership of the overlying land. Under the latter, rights are based on priority of appropriation and beneficial use of water.

The provisions of the ground-water codes of the states may be obtained from state agencies or officials concerned with water and land. These should be complied with by the landowner in the development and use of the water.

7. WELL SITE SELECTION

A geologist familiar with the area should be consulted before a well site is selected. He should have, or obtain, information on wells in the vicinity as to depth to aquifer, pumping head, and quantity and quality of water. Also, he should be familiar with the U. S. Geological Survey publications and studies of ground water in the area. With this background material, he can assist in locating a test hole if one is required or the final well if sufficient information is available.

Spacing of wells is important in planning irrigation developments. When wells are too close together, their areas of influence intersect and prevent maximum production. A minimum spacing of 2,000 feet generally is used for wells producing 600 gpm or more from unconfined aquifers, unless volume and drawdown measurements indicate a smaller or larger radii of influence. See Figure 12-16.

GEOLOGIC INVESTIGATION

A study of the geology and ground-water availability are important in obtaining successful wells. These elements are essential: adequate and dependable water source, sufficient underground reservoir space, and structure or conditions which act to retain water. It is best to determine if these requirements are met before deciding to drill.

Field Office Assistance

In areas where there are wells, a geologist may obtain valuable information from records of materials penetrated, depths to water, and capacities of the wells. Logs of dry holes are also valuable. Field office personnel can help in geologic investigations by assembling records of wells in areas of interest in advance of an examination. They also can assist in field examinations by furnishing information on locations of wells and springs, flow of springs, locations of bedrock exposures, and other geologic features. A geologic reconnaissance with local assistance may develop enough information in a short time to determine the advisability of drilling.

Geologist's Assistance

If there are no wells in an area, the geologist should evaluate possibilities of ground-water development by a study of published information and field investigation. He will need geologic and ground-water maps and reports published by the U. S. Geological Survey, State Geological Surveys, State Bureaus of Mines, universities and colleges, and several technical societies. Geologic reports or maps, aerial photo contact prints and topographic maps at the work unit office should be made available for his use.

Test Holes

The geologist's appraisal of a well site is based on information obtained from study and observation. In most instances, one or more carefully logged test holes of small diameter will prove a sound investment in making the final selection of a well site. Aquifers in alluvium-filled valleys are usually lenticular, or lense-shaped, bodies of sand or gravel in buried channels. Several test holes drilled along a line perpendicular to the valley axis may be necessary to locate the thickest section of permeable materials and the most favorable place for the well. In rock, test holes are of value in determining nature and sequence of strata and geologic structure, as well as conditions of jointing, fracturing, or development of solution passages, in advance of drilling the larger hole. Test holes are especially useful in areas where little knowledge is available or where geologic conditions are complex. Pumping tests may be needed in some test holes and, if so, will require the drilling of 6-inch or larger diameter holes.

Test drilling provides the information and samples needed to design and construct a well capable of developing the full yield of aquifers present. Essential information includes nature, depth to, and thickness of the water-bearing material; nature of the overlying and underlying material; depth to and quality of water. The size, number, and location of casing perforations needed, the need for a well screen, or the need for a gravel envelope may be determined from sieve analyses of aquifer samples and study of the test hole log.

PHYSICAL FEATURES OF SITE

The importance of surface features depends upon the purpose of the well. They may influence choice of the site within limits permitted by geologic conditions.

Domestic Wells

Domestic wells should be convenient for use but located and constructed so as to prevent contamination from surface sources.

Livestock Wells

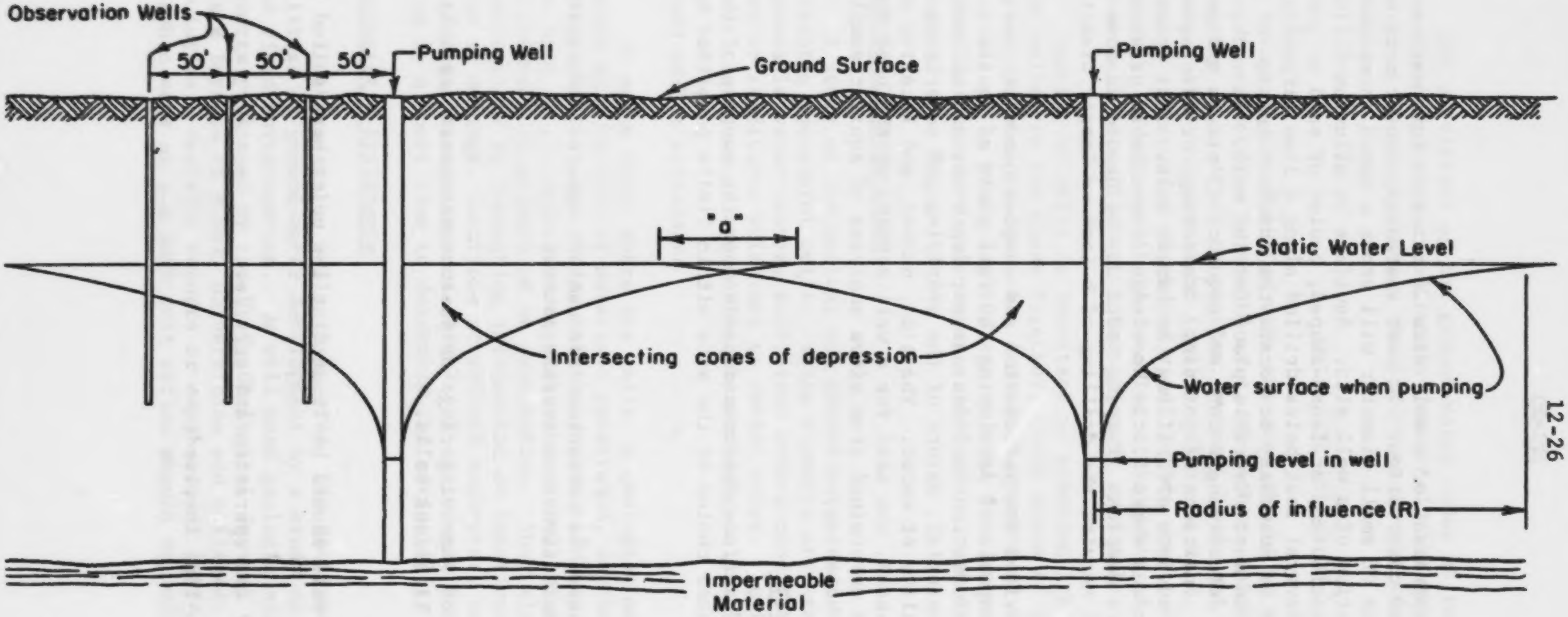
The requirements of improving range or pasture management establish criteria for locating livestock wells.

Irrigation Wells

If feasible, the well should be located at the point best suited for use, considering:

1. Accessibility for operation and service.

2. Length of pipeline involved.


Observation Wells
50'
50'
50'
Pumping Well
Ground Surface
Pumping Well
"a"
Static Water Level
Intersecting cones of depression
Water surface when pumping
Pumping level in well
Radius of influence (R)
Impermeable Material

Wells should be spaced far enough apart so that their radii of influence do not intersect as at "a". Depending upon the permeability of the aquifer and the drawdown, the radius of influence, R, may range from 100 feet to 3,000 feet or more. It may be determined by measuring the depth to water in observation wells spaced at regular intervals away from a pumping well.

Figure 12-16 Well interference in an unconfined aquifer

3. Possible use of gravity flow away from well.

4. Location of storage reservoir, if needed.

If a sprinkler irrigation system is planned, normally the well should be located near the center of the area to be irrigated. The saving obtained through proper location of the well can be considerable, as proper design will allow use of smaller pipe and less main line.

Where surface irrigation with surface ditches is planned, the well is usually located at or near the highest point in the field. Sometimes it is desirable to locate the well below the highest point of the field, but at a point which will permit the use of a minimum amount of pipeline to carry the water to the top of the slope.

Where surface irrigation with portable or underground pipe is to be used, the well should be located where a minimum length and size of pipeline can be used to service the area to be irrigated. This location will depend upon the topography of the field and the design of the water application system.

8. WELL DESIGN

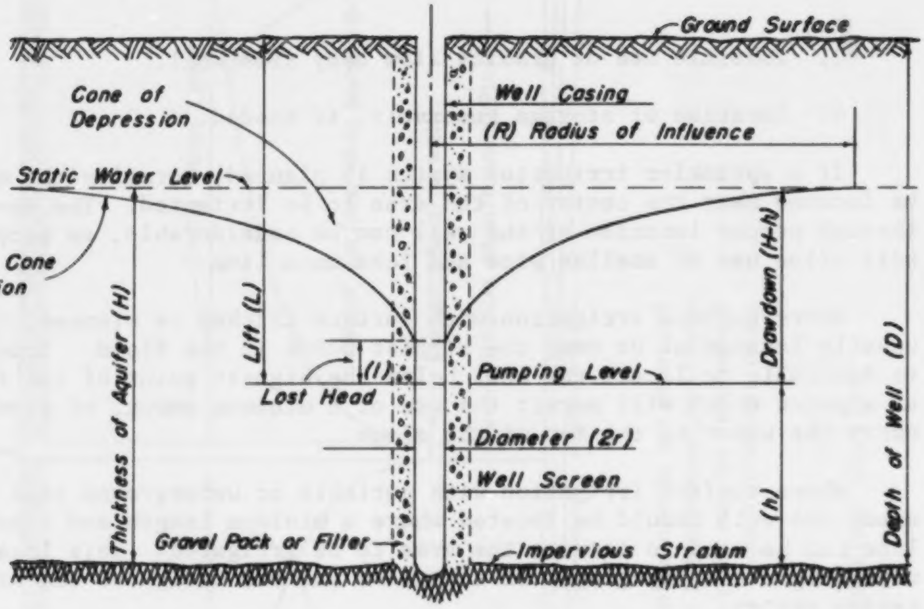
Information needed in designing a well may best be obtained from study of logs and sieve analyses of samples from test holes. Refer to the previous subject, Test Holes, for items to be observed. If test holes have not been drilled, records of nearby wells will be helpful. If no wells have been drilled in the area, a geologic report on the site will provide the best basis for making design decisions.

Design of the well may be most effectively accomplished by the joint efforts of an engineer and a geologist. Decisions regarding the drilling method, diameter, and depth of hole; the position, size, and number of casing perforations; need for a well screen; need for a gravel envelope; and choice of development method will be influenced by geologic, engineering and economic considerations. In some cases, final decisions must be made as the drilling proceeds. Methods of putting essential information together to design the most efficient well are given in the National Engineering Handbook, Section 18, Chapter 7.

Figure 12-17, Typical irrigation well in unconsolidated materials, shows the position of the static water level and the shape of the cone of depression that develops around a pumping well. It also illustrates and defines features and terms commonly used in well design and construction.

9. WATER WELL CONSTRUCTION

Water wells usually are driven, jetted, or drilled. Each method has advantages. Choice of method is influenced by depth to the water table, nature of the soil or rock in which water occurs, nature of the overburden material, and volume of water desired. See Exhibit 12-2.


Ground Surface
Cone of Depression
Well Casing
(R) Radius of Influence
Static Water Level
Profile of Cone of Depression
Thickness of Aquifer (H)
Lift (L)
(l)
Lost Head
Pumping Level
Drawdown (H-h)
Diameter (2r)
Well Screen
(h)
Depth of Well (D)
Gravel Pack or Filter
Impervious Stratum

Definition of Terms

1. Static Water Table. The surface level of the groundwater at the top of the saturated zone in a water-bearing formation is known as the water table.

2. Cone of Depression. As water approaches a well which is being pumped, the slope of the water table increases. As distance from the well increases, the slope becomes flatter until it merges with the water-table level beyond the influence of the well. The water surface in the influence of a pumped well is an inverted cone with its apex in the well and its base in the static water table. This is known as the cone of depression.

3. Area of Influence and Circle of Influence. The area affected by the discharge from a well is known as the area of influence. The boundary of the area of influence is known as the circle of influence. The radius of the circle is the radius of influence (R).

4. Profile of Cone of Depression (Drawdown Curve). If a cross section is made through a pumped well, as shown in the sketch, the water table appears in profile and is known as the profile of cone of depression.

5. Thickness of Aquifer (H). Saturated thickness before pumping.

6. Pumping Level (h). Depth of water in well while pumping.

7. Drawdown (H-h). Drawdown is defined as the distance from the position of the static water table before pumping to the level of the water in the well during pumping.

8. Lift (L). The term lift or head as applied to a pumped well is defined as the vertical distance from the water level in the well during pumping to the ground surface or some other specified point as the center of the discharge pipe.

9. Lost Head (l). Lost head is defined as the difference in elevation between water level inside the well (during pumping) and outside at the point where the drawdown curve intersects the casing.

10. Gravel Pack or Filter. A gravel envelope surrounding the casing and designed to prevent surrounding sand from entering the well.

11. Well Casing. A rigid pipe installed in the well to prevent the walls of the well from sloughing into the well.

12. Well Screen. A perforated or slotted section of pipe used to separate the water from the surrounding aquifer.

Figure 12-17 Typical irrigation well in unconsolidated materials

DRIVEN WELLS

The use of driven wells is limited to areas underlain by unconsolidated clay, silt and sand relatively free of gravel, cobbles, or boulders. Depth to water, including drawdown, must be less than the suction limit at the elevation of the well. The practical limit of suction lift for pumps is 22 feet at sea level, 17 feet at 5,000-foot elevation, and 14 feet at the 10,000-foot elevation.

Driven wells are constructed by driving pipe fitted with a sand point sufficiently below the water table to insure that fluctuations and drawdown from pumping will not lower the water below the sand point.

A sand point consists of a forged steel point attached to a short length of perforated pipe. The perforated pipe is wrapped with either brass screen or spiral-wound brass bands having a trapezoidal cross section. The bands form a nonclogging slot that is narrowest at the outside and flares to greater width against the pipe.

In driving the point through materials containing considerable amounts of clay, the openings often become clogged. It may be advisable to auger or jet the hole through the clay layers. Augering is the most effective method of penetrating and removing clay.

A single driven well is an efficient and economical means of obtaining small amounts of water under the conditions outlined. A series of driven wells connected to a common pump manifold may be useful in developing irrigation supplies.

The central pump lifts water from each of the wells of a well-point system by producing a partial vacuum in the header and riser pipes. The partial vacuum, or suction head, that the pump can maintain determines the level to which the water can be pulled down in the wells and in the water-bearing sand. Thus, a pump that has good suction characteristics should be selected.

As no two wells in the system will pump exactly alike, it is often necessary to regulate the yield and drawdown in one or more of the wells individually to balance the system properly. This can be done readily if a valve is provided in the branch connection from each wall to the suction header. The valve also permits isolating each well for repair or cleaning without shutting down the rest of the wells.

Sand Point Installations

The layout of a sand point system can be adapted to any of several patterns. Straight line, angle, circular, and "H" forms are illustrated in Figure 12-18. Locating the wells on the circumference of a circle gives the greatest hydraulic efficiency.

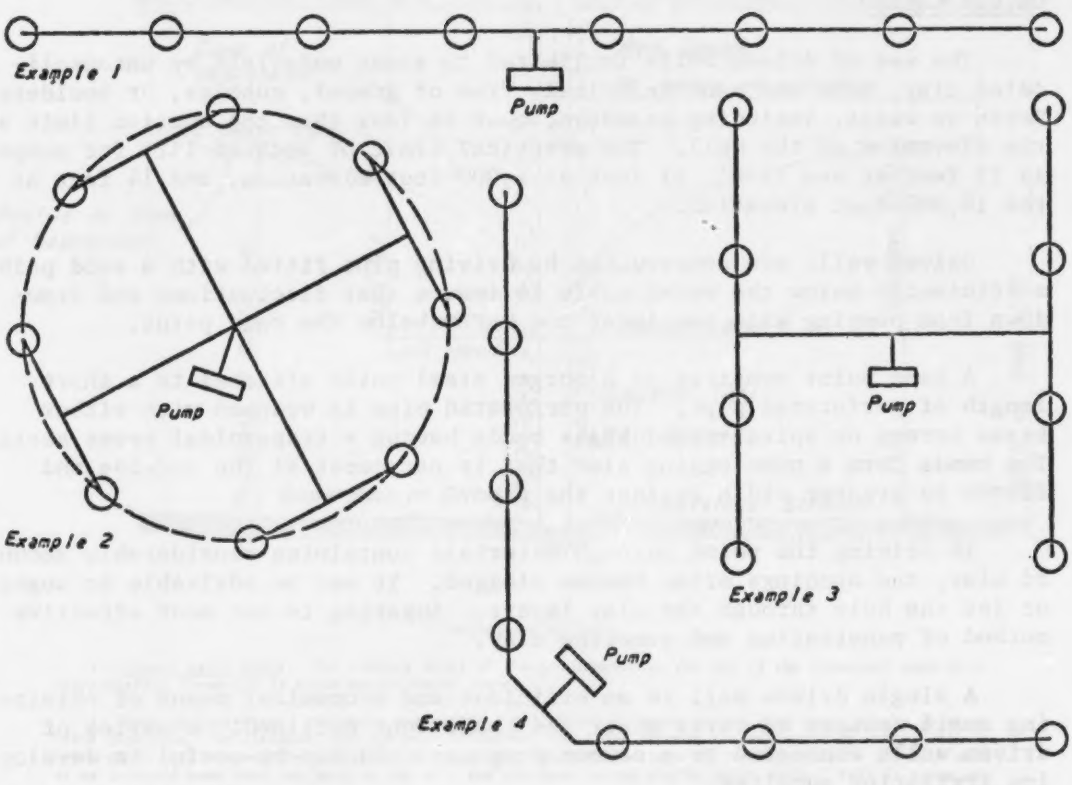


Figure 12-18 Examples of layouts for manifold pumping systems

If the groundwater is flowing along a buried stream channel, sand points should be spaced in a line at right angles to the direction of flow. If the water-bearing material contains fine sand and gives up water slowly, wells should be located on the circumference of a circle giving the effect of one large well.

No exact spacing of the sand points can be set. Sometimes the water supply will be adequate on 10-foot spacings. However, it is good practice to space sand points at least 40 feet apart so interference between them will be at a minimum. After the first point is set, the remaining points can be set by connecting the pump discharge to them and jetting them into place.

The water-bearing sand should be analyzed to determine the size of screen openings, or size of filter material needed. If gravel treatment is not needed, the general practice is to drill or auger one hole and install a 2- to 4-inch pipe with a sand point 2 to 3 feet long. Connect a small centrifugal pump to this pipe and measure the discharge. Additional wells are then installed. If the water supply is good and the well properly installed, each of the added sand point installations should furnish approximately 75 percent of the measured amount of the first well. Figure 12-19, shows details of design and construction for a typical four-well battery installation.

JETTED WELLS

Use of a high-pressure stream of water through a chisel-pointed bit combined with a chopping action is effective in sinking small diameter holes to shallow depths in silt, sand and small gravel. Holes up to 3-inches in diameter and 30-feet deep are quickly jetted in soft materials. Cuttings are washed to the surface. Jetting is often used to supplement driving in setting sand points, some of which have jetting nozzles. Holes are cased through caving materials. When the sand point and well pipe are set the casing is removed. Jetting equipment is portable and inexpensive.

DRILLED WELLS

Most wells are now put down by drilling. They are drilled in any material to any suitable depth. Holes usually are advanced by one of two methods, percussion drilling or hydraulic rotary drilling. A new method of drilling combines air removal of cuttings with percussion and rotary methods of advancing the hole. It is used successfully in oil exploration and holds promise for water-well drilling.

There are various modifications of the two common methods developed to meet geologic conditions in particular localities. The California or "stovepipe" method, also called the "mud-scow" method, is efficient in unconsolidated clay, silt and sand where the water table is at shallow depth. The sand-pump, orangepeel bucket, and jetting methods also are adapted to these conditions. The hollow rod or self-cleaning method is satisfactory for drilling in uniform and relatively fine-grained sediments. It maintains the relative position of cuttings in the combination bit and bailer.

The percussion or cable tool method may be used to drill all materials. An accurate log of materials penetrated may be made by bailing the hole and examining the cuttings at changes in formation. The method is especially effective in developing small amounts of water because the wells are continually washed by the churning action caused by lifting and dropping the tools. Less water is required for drilling with cable tools than with the rotary method.

The cable tool method is not adapted to drilling in loose or caving material without casing. Because of this requirement, it is slower than rotary drilling in such materials. Casing often must be left in unsuccessful holes because squeezing and flowage of soft or loose material prevents removal.

The hydraulic rotary method is effective for drilling most rocks. The hardest rock may be drilled with calyx shot, bort, and diamond bits. Drilling is rapid in all except the hardest rocks. Difficulty is encountered in penetrating loose, hard boulders. Casing is not usually required for drilling soft formations because pressure of the drilling mud supports the walls and reduces the tendency to cave. Holes of larger diameter may be drilled with the rotary method rather than with cable tools, an advantage in constructing gravel envelopes for wells, especially when more than one aquifer is to be developed.

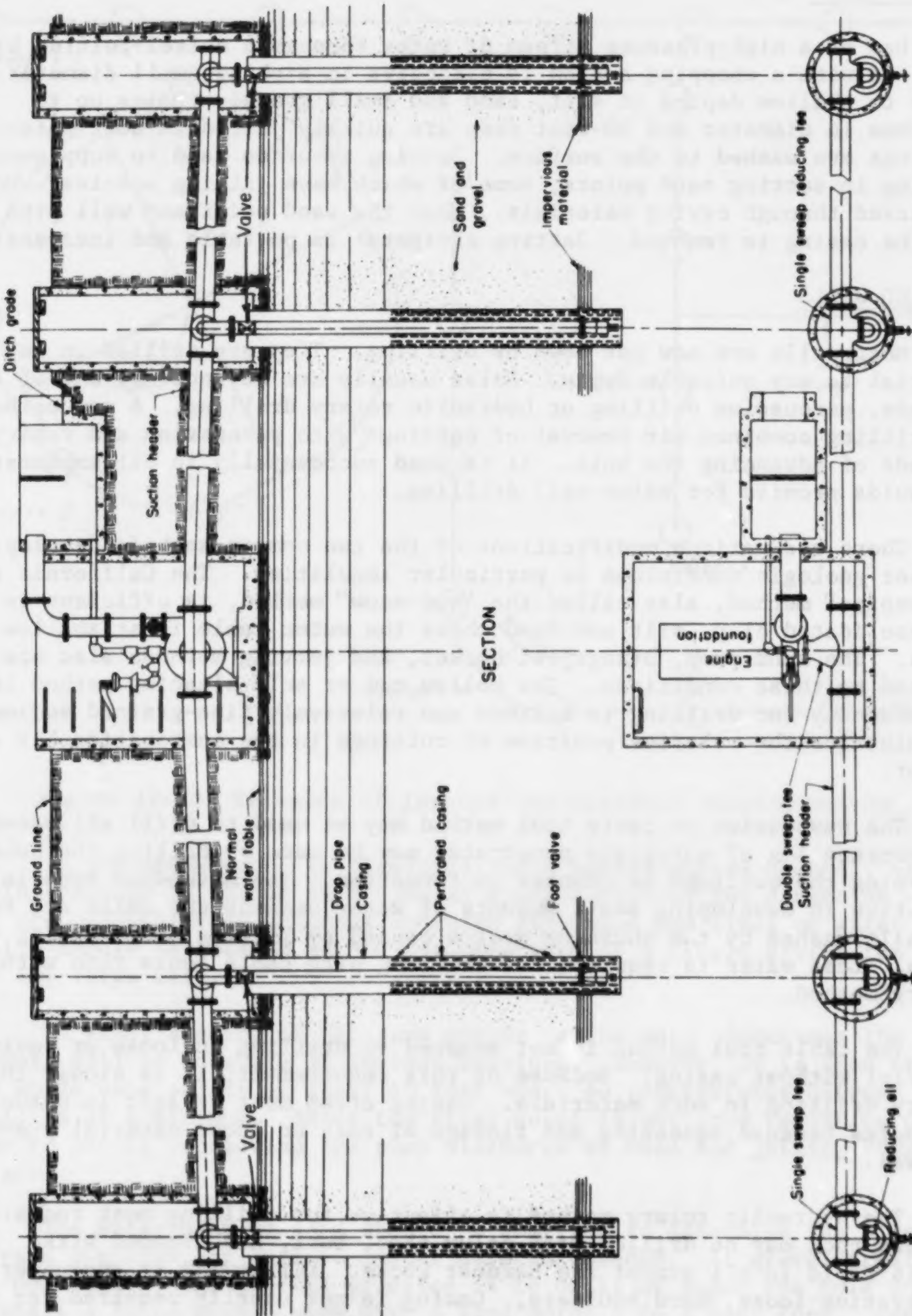

Ditch grade
Suction header
Valve
Sand and gravel
Impervious material
Single sweep reducing tee
Engine foundation
SECTION
PLAN
Ground line
Normal water table
Drop pipe
Casing
Perforated casing
Foot valve
Double sweep tee
Suction header
Valve
Single sweep tee
Reducing ell
Drawdown

Figure 12-19 Typical four-well battery installation

Logs of materials penetrated are prepared by periodic examination of cuttings brought up in the drilling fluid. Systematic sampling and a drilling-time log are needed to identify depths of change in materials.

Mud used to remove cuttings tends to seal the formations and may prevent small flows of water entering the hole. After casing is installed, the aquifer walls are washed to remove mud and develop full flow into the well.

The reverse hydraulic rotary method is especially adapted to drilling holes of large diameter (16 to 48 inches) in alluvial materials because of efficient removal of cuttings. With this modification of the rotary method, cuttings are brought to the surface inside the drill pipe by suction. Water is used instead of drilling mud. The method provides much higher upward velocity within the drill pipe or rods than can be attained outside the rods in a large hole by the conventional method. The walls are supported by pressure of the drilling water.

AUGERED WELLS

Augering is the simplest rotary method. The hole is advanced by bits of several designs that dig into the ground as they are rotated. A common type has two inclined blades mounted below a cylinder or slat-enclosed section for containing cuttings. Cuttings are raised to the surface by lifting the bit or by spiral plates continuing up the stem on flight augers. Wells may be augered in unconsolidated deposits that stand unsupported and contain no material larger than medium gravel (1 to 2 inches).

Hand augers up to 8 inches in diameter are used with pipe extensions for holes to about 30 feet in depth. Power augers usually have a maximum diameter of 36 inches and under favorable conditions dig to a depth of about 70 feet. Casing may be required below the water table and usually is needed to support thick layers of sand or gravel above the water table. Augered wells are economical for the depths and conditions described.

CASING

Casing maintains the hole through loose, caving, or flowing materials and seals out contaminated or undesirable waters. It must be strong enough to resist earth pressure and, depending upon method of placement, may have to withstand considerable shock and compressive stress. Casing should be sufficiently resistant to corrosion to last 25 to 50 years.

Materials

Most wells are cased with steel or wrought iron pipe using welded or threaded and coupled joints. When the casing is to be driven, a steel drive shoe is riveted or welded to the bottom of the pipe to ream the hole and prevent crimping the casing. Casings of other materials and designs are used with special drilling methods adapted to specific geologic conditions.

"Stovepipe" or double casing made up of telescoping sheet iron sections, 8- to 16-gage in thickness, 2 to 4 feet in length, and 4 to 36 inches in diameter, is used in sediment-filled valleys in California and Arizona. It was designed for use with the mud scow, orangepeel bucket, and hollow-rod drilling methods. Casings of concrete, tile, and wood also have been successfully used. Riveted, single-thickness sheet-iron casing joined by telescoping or welded joints is sometimes used.

No one metal or alloy resists corrosion better than all others in all soils, but suitable material may be obtained for each condition. Copper and alloys high in copper corrode slowly in most soils but corrode at their highest rate in soils containing sulfides. For all copper alloys the rates of corrosion were higher in cinders than in any soil tested. Aluminum and some of its alloys corroded rapidly under most of the soil conditions to which they were exposed.

Steel or wrought-iron pipe, while not corrosion resistant, has adequate life as well casing under most conditions because it is over strength. The use of heavy pipe is an economical means of obtaining long life even in fairly corrosive materials.

Under especially corrosive conditions, pipe and tubing of stainless steel, brass and copper alloys containing manganese, nickel and silicon have been used. Joints are welded because the wall thickness is less than for steel or wrought-iron pipe. Asbestos-cement pipe is suitable for casing and plastic pipe has recently been used in wells up to 6 inches in diameter. Fiberglass epoxy water-well casing has high strength and has shown high resistance to corrosion. Use of cast-iron casing is increasing. Pipe lined with cement, various enamels, and rubber is available and may prove useful in some situations. Asbestos-cement, plastic, and cast-iron pipe have slip joints. Lined pipe has flanged joints. The well construction method must allow these casings to be set in place without driving.

Thicknesses of steel or wrought-iron casing considered "best practice" are:

Inch diameter	Inches
6	0.280
10	0.365
12-20	0.375
22-36	0.500

Steel and iron pipe have standard dimensions, weight and threading. Refer to ASTM A-53, ASTM A-120 for specifications.

Pipe is commonly furnished in 20-foot lengths. Sizes up to 12 inches are designated by nominal inside diameter. Sizes 14 inches and over are designated by outside diameter. When ordering, specify the desired wall thickness, or weight per foot. In some areas the inside diameter and wall thickness are specified for pipe made to order. Galvanized pipe may be purchased in sizes up to 12-inch diameters. Larger sizes may be galvanized by arrangement with the manufacturer.

The method of placing the casing and conditions of service should be considered in selecting the weight of pipe to use. Heavier walls are needed for hard driving and corrosive environment. Lighter pipe may be used where conditions are unusually favorable. Threading data must be specified for diameters 14 inches and over, as these are generally stocked with plain ends. Welded joints are advocated for pipe larger than 20 inches in diameter and also for smaller sizes, where applicable, to obtain hole clearance or maintain uniform grout thickness.

Screens

Well screens are installed at the lower end of the casing to retain the coarser aquifer materials about the well and permit removal of finer materials by development. They must have an open area of at least 15 to 20 percent to keep entrance head losses at a minimum.

Screens are manufactured according to several designs and from a variety of corrosion-resistant materials. One popular type features a continuous horizontal slot formed by wrapping and welding trapezoidal wire about a cylindrical frame of rods. The slot opening is determined by the spacing between the trapezoidal wire wraps and is varied according to specifications. The wire is placed with the wide side out, resulting in an opening that widens toward the inside of the screen. This inward flaring slot reduces clogging of the screen to a minimum. A type having sectioned horizontal slots is made by wrapping trapezoidal wire over metal strips on perforated steel tubing. The trapezoidal wire is formed with lateral lugs at intervals to maintain the slot width. Another perforated pipe design is like a sand point but much larger. It consists of woven screen of various gages wrapped on casing perforated with 5/8-inch holes. The screen is protected by 1/2-inch mesh galvanized iron hardware cloth. Other screens are galvanized iron casing with punched openings in lattice, crowfoot, shutter or louvered slit design. Louvered horizontal openings are reported more effective in controlling unconsolidated materials than vertical slots.

The size of screen openings is determined on the basis of sieve analyses of aquifer materials. The opening or slot size should be such that 20 to 40 percent of the materials are larger than the opening.

The uniformity coefficient is a means of rating uniformity of grain size and is expressed by the formula

$$C_u = \frac{\text{D60 size}}{\text{D10 size}}.$$

A uniformity coefficient of unity means that the grains of material are practically all the same size, while a large coefficient indicates a large range of sizes.

If the uniformity coefficient of the aquifer material is 2.0 or less, the screen should have an artificial gravel envelope. If no coarse particles (between 0.5 and 1.0 mm.) are present, an artificial gravel envelope will be required even though C_u is greater than 2.

Well screen manufacturers usually will make tests of formation samples and recommend the size or sizes of screen openings best suited for a particular grain size distribution, as well as the best metal to use for screens based on the characteristics of the water.

10. WELL DEVELOPMENT

The purpose of development is to condition the well to produce the maximum amount of sand-free water with minimum drawdown. Development is the last operation in constructing a well. It is the mechanical removal of fine sand, silt and clay from about the well, thereby forming a natural gravel envelope. Or, if no coarse particles are present, it removes fines through an artificial gravel envelope. Development is essential to satisfactorily complete wells in unconsolidated materials and has proved beneficial in consolidated deposits in some instances. The following discussion relates to development in unconsolidated deposits.

Wells may be developed using one or a combination of methods, including surging, backwashing, jetting, use of compressed air, pumping, use of dry ice, acid, and dispersing agents. Some are more effective under certain conditions than others. Knowledge of drilling methods and how particular formations react to development is required for proper selection.

Care must be taken in developing wells. Information from the record of materials penetrated is used to guide development work. Operations such as pumping, surging, jetting and backwashing should start slowly.

Bridging of fine sand in the aquifer close to the well may result from too violent action at the beginning of work. When water is pumped from a well, there is a tendency for sand particles in the formation to move toward the well. Because the steady pull of pumping is in one direction, finer sand grains wedge against each other and bridge across openings between coarser grains. The only way bridging can be prevented and fine grains removed is by keeping the water agitated by reversing the direction of flow.

Results should be carefully observed and the tempo of operations increased only if the method is operating as expected. If the aquifer is overlain by fine sand or silt, there is danger these materials may be washed down into the aquifer by surging and spoil the well or prolong development work. See National Engineering Handbook, Section 18, Chapter 7.

11. WELL TESTING

Test results show well characteristics and permit estimating optimum pumping rate, pump setting, pump capacity and power required. Testing is done after completing the development and preferably after 30 days of steady pumping.

The optimum yield and required lift may be estimated by converting drawdown, obtained from the tests, to percent of possible drawdown and reference to Exhibit 12-3. The curves shown are average drawdown-yield relations for a large number of wells. It is noteworthy that nonartesian wells obtain about 77 percent of possible yield at 50-percent drawdown and artesian wells produce about 55-percent yield at 50-percent drawdown.

TEST PROCEDURES

The following testing procedures are recommended:

1. Measure and record depth to static water level. (May be measured with steel tape that has 1 to 2 feet of its lower end chalked.)
2. Determine if the well is artesian or nonartesian by reference to the well log for presence of a confining layer. If the static water level is above the bottom of the confining layer, the well is artesian.
3. Figure height of the static water column or 100-percent drawdown. For nonartesian wells, 100-percent drawdown is the depth from static water level to the bottom of the aquifer, or to the bottom of the well if the aquifer is not completely penetrated. For artesian wells, 100-percent drawdown is the depth from static water level or piezometric surface to the bottom of the confining layer.
4. Pump the well at near maximum rate (50-percent drawdown or slightly more) until drawdown and yield are constant at that rate. Drawdown may be considered constant when three measurements taken one hour apart are the same. Measurement of water levels while pumping should be made with an electric sounder or air line. Several hours to several days of continuous pumping may be required. Record drawdown and yield.
5. Convert measured drawdown to percent drawdown and refer to Exhibit 12-3 to estimate optimum drawdown and yield.

ESTIMATING YIELDS AND DRAWDOWNS

After a pumping test has been made, Exhibit 12-3 may be used to estimate the most economical water yield from a specific well, as shown in the example thereon.

MEASURING DRAWDOWNS

There are two satisfactory methods of measuring drawdown in wells. Many deep-well pumps are equipped with pressure gages and air lines of known lengths. The air line is simple to install and operates automatically. Air lines should be made a part of each pump installation so that frequent measurements of water level can be made.

The air line is usually a copper tube 1/8 to 1/4 inch in diameter but may be 1/4-inch galvanized pipe. Its surface end is connected to a pressure gage with an air valve just below the gage. See Figure 12-20. The lower end of the pipe is open. The pipe must be airtight and should extend 20 feet or more below the lowest pumping level. The depth to the lower end of the air line must be accurately known. Air pressure can be furnished by a tank connected to the line or by means of an ordinary tire pump. The gage indicates pressure necessary to counterbalance the depth of water outside the air line. This is maximum pressure that can be attained.

Practically all gages are now calibrated in feet, so that direct readings of water level above the end of the air line can be made. Depth to water level is the depth to the lower end of the air line less the gage reading in feet. (If the gage reads in pounds per square inch, multiply reading by 2.31.)

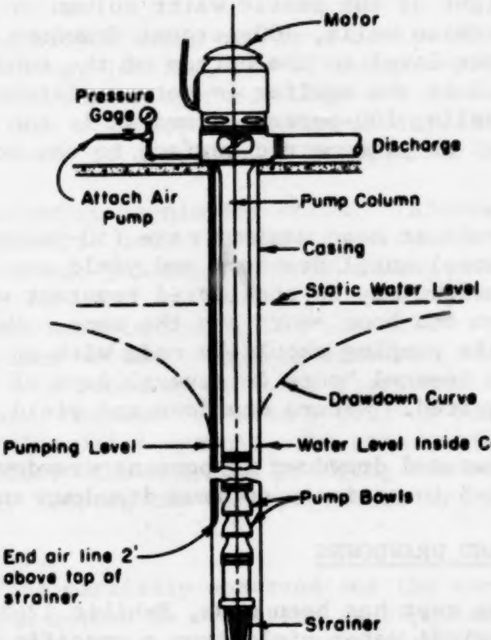

Motor
Pressure Gage
Discharge
Attach Air Pump
Pump Column
Casing
Static Water Level
Drawdown Curve
Pumping Level
Water Level Inside Casing
Pump Bowls
End air line 2' above top of strainer.
Strainer

Figure 12-20 Air line for measuring depth to water level

Another satisfactory and accurate method of measuring water level is by means of an electric sounder. There are several types of sounders but the basic principle is the same. An electric sounder can be made using two-strand insulated electrical wire with one end shielded to form an electrode. At the surface the wires are connected to flashlight batteries in series with a sensitive ammeter. When the electrode is lowered into the well, the electric circuit is completed when ends of the wires touch water. Contact is registered on the ammeter.

It will be found that even careful measurements of drawdown will vary for the same yield. The water level in a pumping well is constantly moving. Usually it is going down, slowly but steadily.

MEASURING YIELD

An accurate well test requires careful measurement of yield. Pipe orifices are commonly used to measure discharges within a range of 50 to 2000 gallons per minute. Parshall flumes or sharp-crested weirs are used to measure larger flows. See SCS National Engineering Handbook, Section 15, Chapter 9, Measurement of Irrigation Water, and Chapter 3 of this manual.

12. PUMPING

SELECTION OF PUMP

In selecting a pump, consideration should be given to required capacity, total lift, diameter of the well, location of the well, and type of power available. The common types of pumps are turbine, centrifugal, propeller, gear, plunger and airlift. Each pump is constructed to meet a range of conditions. The selection of a pump should not be made without a thorough investigation. Refer to National Engineering Handbook, Section 15, Chapter 8.

POWER REQUIREMENTS

Power required for operating a pump is determined by the amount of water to be pumped in a period of time, the height to which it must be pumped, the head losses, and the efficiency of the pump. The required brake horsepower =

$$\frac{\text{gallons per minute} \times (\text{total lift in feet} + \text{head losses})}{3960 \times \text{efficiency of the pump} \times \text{efficiency of drive}}$$

The well owner should look to the manufacturers of pump and power units for guidance in selecting the proper kind and size of units.

TYPES OF POWER UNITS USED FOR PUMPING WATER

Electric Motors

Where electricity is available at reasonable rates it is the most satisfactory source of power for irrigation pumping. An electric motor properly selected and protected can be expected to furnish trouble-free power for many years.

Advantages of electric power are low cost of electric motors, their reliability, high efficiency, and low cost of upkeep. An electric motor will deliver full power throughout its life. Disadvantages of electric power are power interruptions, the need to construct an electric supply line to each pumping location, and if only single-phase current is available, the additional cost of single-phase motors of more than 2 horsepower or the cost of a phase converter to permit use of a three-phase motor. Also, the capacity of many single-phase lines limits the power of motors that can be used to about 7-1/2 horsepower.

The 60-cycle, 220 or 440 volt, three-phase, squirrel cage induction motor is the type most generally used for pumping plants.

Internal Combustion Engines

The rated horsepower of internal combustion engines is greatly in excess of the horsepower they can be expected to produce on a sustained basis. The kind of fuel, accessories, and type of cooling system used, as well as temperatures and elevation, must be considered when selecting internal combustion engines. The fuel may be gasoline, kerosene, diesel oil, propane, butane or natural gas. The cooling system may use water or air.

Because altitude and air temperature affect horsepower output, and engine ratings are based on sea level and 60° temperature, it will generally be necessary to make corrections for most irrigation pumping installations. General rules for correcting for elevation and temperature are:

1. Reduce continuous load rating 3 percent for every 1000 feet above sea level.

2. Reduce continuous load rating 1 percent for every 10° F. above 60° F.

In addition to the above reductions, the rated horsepower should be further reduced 5 to 10 percent for power consumed by accessories (fan, generator, water pump) and 15 to 20 percent for reduction in power due to continuous service. Reference should be made to National Engineering Handbook, Section 15, Chapter 8, for the details of applying these reductions.

Windmills

Windmills can be used to pump small quantities of water for livestock or domestic use. Enough water for irrigation of a small plot may be pumped if storage facilities are provided. A windmill can be expected to produce from 0.2 horsepower for a 6-foot mill to 2.0 horsepower for a 16-foot mill during periods of optimum wind movement. They are best adapted for use with a plunger-type pump. To obtain best results, the windmill and pump cylinder must be selected to utilize the prevailing wind velocity.

The mill should have sufficient power to pump the quantity of water specified. Exhibit 12-4 gives the approximate quantity of water delivered when the mill is operating in a wind strong enough to run at its maximum number of strokes. When the prevailing winds are light or variable, where the wind usually blows only a few hours each day, or where the exposure is poor, an oversized mill should be selected. Pumps and cylinders used with the various sizes of mills should be capable of giving a clear stroke equal in inches to the diameter of the windmill in feet; for example, 8 inches for the 8-foot mill and 10 inches for the 10-foot mill. The capacities shown in Exhibit 12-4 are based on the long stroke of the mills. When the short stroke is used the capacity should be reduced about 25 percent. Use of the short stroke is not recommended except under conditions when it is required to fit an existing pump installation.

Towers may be built of either wood or steel. Woodtowers have the advantage of greater stability during high winds and they do not attract lightning as much as steel. The tower should have sufficient height to put the wheel above all wind obstructions.

13. MISCELLANEOUS

CONTRACTS AND SPECIFICATIONS

Few individuals take the trouble to draw up a contract when having a well drilled. Although an oral contract is binding on both parties, it could be a source of misunderstanding because it depends upon the memory of the parties. On the other hand, a contract and specifications which are too rigid lead to excessive costs and should be avoided.

When a legal contract is required the landowner should be encouraged to consult an attorney. A thorough understanding and agreement on at least the following points are necessary if a satisfactory job is to result.

1. The well shall be started at the surface with ______ inch _______ pipe with a weight per foot of ______ pounds, and carried to a depth of about ______ feet. If two or more lines of casing are run, an ample overlap will be allowed and an effective seal will be set.

2. The well shall be drilled in such vertical alignment that, after perforating and testing, a deep-well pump having a clearance of 1 inch on each side may readily be installed and operated without undue stress or wear due to excessive inclination of the shaft.

3. As construction progresses the contractor shall keep, and furnish to the owner on completion of the well, an accurate record of materials passed through, water-bearing strata, progress in sinking the casing, depth, size and number of perforations or screen opening and dimensions, static water level, development work, drawdown and record of testing.

4. The casing will be perforated in all water-bearing strata (except quicksand)likely to yield a satisfactory supply of good quality water.

   The sizes of perforations will be determined on the basis of grain-size distribution of aquifer materials according to best practice.

5. Advisability of installing a well screen and/or an artificial gravel envelope will be determined on the basis of grain-size distribution of aquifer materials according to best practice.
6. After completion, the well shall be surged thoroughly with a surge block, bailer or other equipment, until sand-free water is obtained. The work of surging or other development shall be paid for at the rate of _____ per hour.
7. After the well has been surged and bailed, it shall be tested with a pump furnished by the driller. Pump shall have a capacity in excess of expected yield and be capable of pumping at variable rates. The pump shall be operated continuously for a total of _____ hours. An air line or other suitable method shall be used to measure the drawdown periodically during pumping.
8. The unit price per foot of well will be _____ and include the cost of moving to and from the well site and setting up the equipment. The cost of perforating will be included in the unit price unless otherwise stated. Test pumping will be paid for at the rate of _____ per hour and will include time of installing and removing the pump.

In case a dispute might arise, the procedure to be followed in settling the dispute should be set forth in the contract. Large well drilling companies have their own contract forms. In case they are used, the landowner should be encouraged to read their provisions carefully before signing so that he will understand the agreement.

WELL RECORDS

Maintenance of complete records aids efficient and economical ground-water development. Therefore, copies of the records of test holes, completed well and equipment, development operations, and pumping tests should be retained in the work unit and other Service offices in the state as required.

DISCHARGE THRU PIPE "FLOWING FULL" GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME FRICTION LOSS PER FOOT OF PIPE

GALV. IRON PIPE, NEW TO FAIR COND.
n = 0.014 (MANNING'S)
c = 110 (HAZEN-WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT.) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n=0.014	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.2	0.4	0.6	0.8	1.0	1.5	2.6
45° ELBOW (STANDARD)	0.2	0.3	0.4	0.6	0.7	1.1	1.9
GATE VALVE (OPEN)	0.1	0.2	0.3	0.3	0.4	0.6	1.1
CONTRACTION ($\frac{d_1}{d_2} = 1.5$)	0.1	0.2	0.2	0.3	0.4	0.5	1.0

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in Gal./Min.

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in Ft./Ft. = h_f/L

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

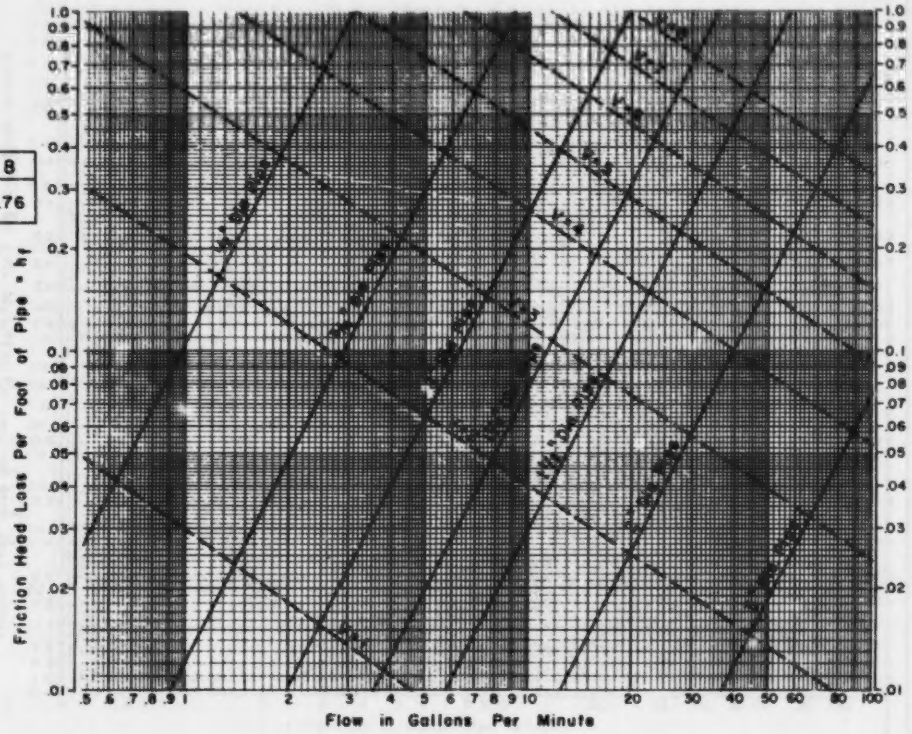


Exhibit 12-1 Discharge through pipe flowing full

(Sheet 1 of 3)

DISCHARGE THRU PIPE "FLOWING FULL" GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME FRICTION LOSS PER FOOT OF PIPE

GALV. IRON PIPE, OLD TO POOR COND.
n=0.017 (MANNING'S)
c = 95 (HAZEN - WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n=0.017	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.2	0.3	0.4	0.6	0.7	1.0	1.8
45° ELBOW (STANDARD)	0.1	0.2	0.3	0.4	0.5	0.7	1.2
GATE VALVE (OPEN)	0.1	0.1	0.2	0.2	0.3	0.4	0.7
CONTRACTION($\frac{d_1}{d_2}$ = 1.5)	0.1	0.1	0.1	0.2	0.2	0.4	0.6

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in Gal./Min.

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in Ft./Ft. = h_f/L

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

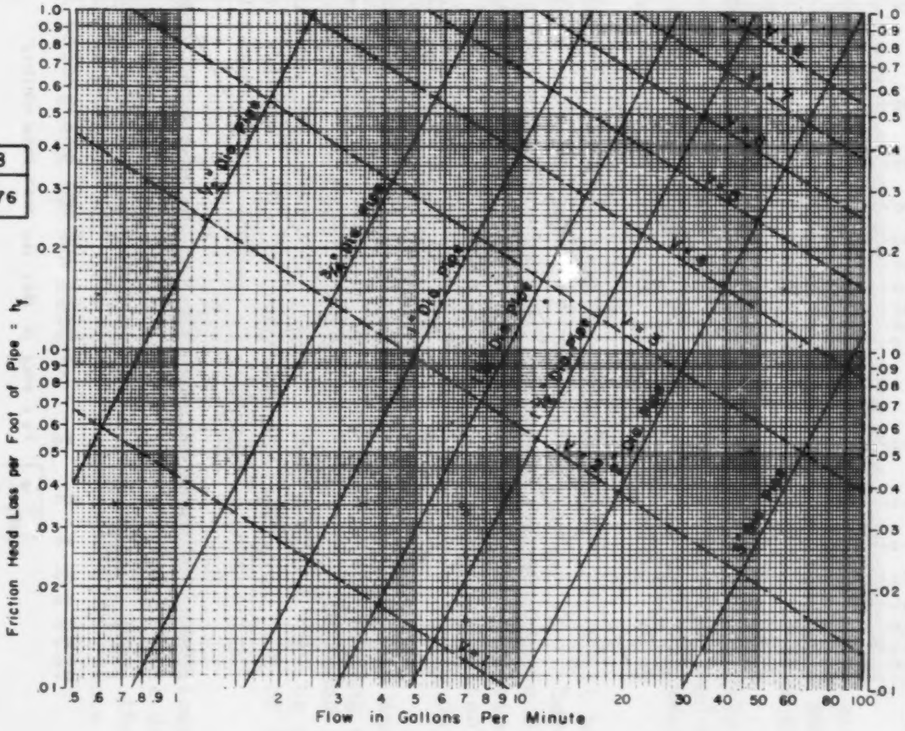


Exhibit 12-1 Discharge through pipe flowing full

(Sheet 2 of 3)

DISCHARGE THRU PIPE "FLOWING FULL" GALLONS PER MINUTE VS. HEAD IN FEET REQUIRED TO OVERCOME FRICTION LOSS PER FOOT OF PIPE

PLASTIC OR COPPER PIPE
n = 0.009 (MANNING'S)
c = 140 (HAZEN - WILLIAMS)

CHART I

VELOCITIES	1	2	3	4	5	6	7	8
MIN. HEAD (FT.) REQ. OVER ENTRANCE (He)	0.03	0.11	0.25	0.45	0.69	1.0	1.35	1.76

CHART II

EQUIVALENT LENGTHS OF PIPE

n = 0.009	DIAMETER						
	1/2	3/4	1	1 1/4	1 1/2	2	3
90° ELBOW (STANDARD)	0.6	1.0	1.4	2.0	2.5	3.7	6.3
45° ELBOW (STANDARD)	0.4	0.6	1.0	1.3	1.7	2.4	4.2
GATE VALVE (OPEN)	0.2	0.4	0.6	0.8	1.0	1.5	2.6
CONTRACTION ($\frac{d_1}{d_2} = 1.5$)	0.2	0.3	0.5	0.7	0.9	1.3	2.2

Mannings Formula: $Q = \frac{0.276}{n} d^{8/3} s^{1/2}$

Q = Quantity of Flow in $\mathrm{Gal.}/_{\mathrm{Min.}}$

d = Diameter of Pipe in Inches

n = Coefficient of Roughness of Pipe

s = Hydraulic Gradient in $\mathrm{Ft.}/_{\mathrm{Ft.}} = h_f/_L$

h_f = Friction Head Loss in Feet

L = Length of Pipe in Feet

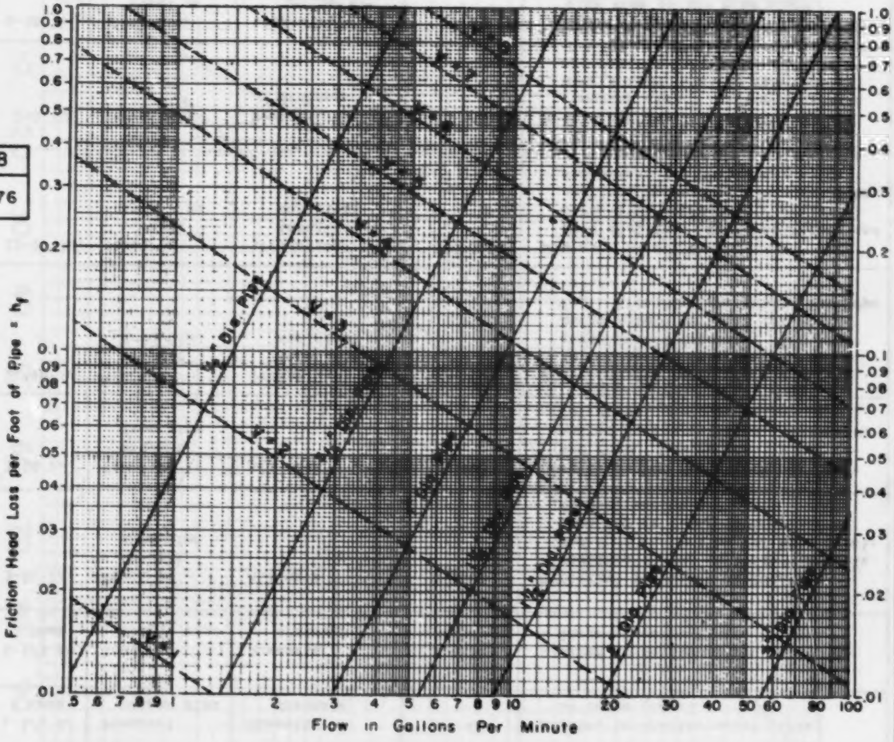


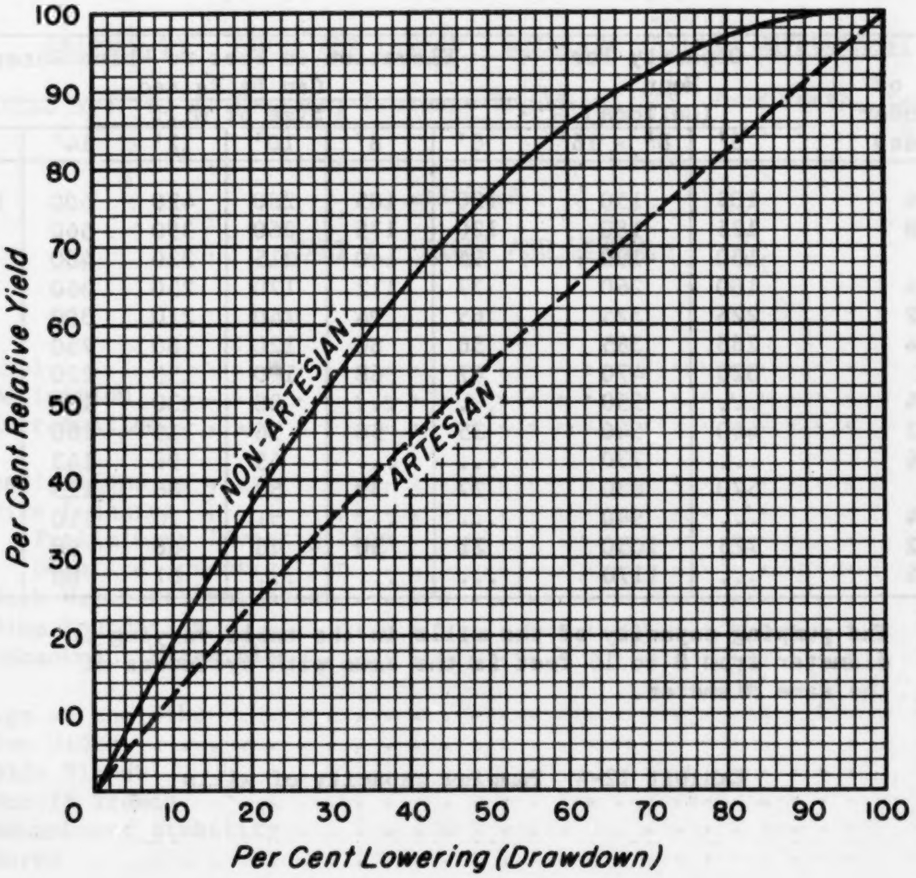
Exhibit 12-1 Discharge through pipe flowing full

(Sheet 3 of 3)

Method	Materials for Which Best Suited	Water Table Depth for Which Best Suited (feet)	Usual Maximum Depth (feet)	Usual Diameter Range	Usual Casing Material	Customary Use	Yield 1/ (g.p.m.)	Remarks
Driven Wells Hand, air hammer	Silt, sand, gravel less than 2 inches.	5 - 15	50	1-1/4 to 4 inch	Standard weight pipe	Domestic, drainage	3 - 40	Limited to shallow water table, no large gravel.
Jetted Wells Light, portable rig	Silt, sand, gravel less than 1 inch	5 - 15	50	1-1/2 to 3 inch	Standard weight pipe	Domestic, drainage	3 - 30	Limited to shallow water table, no large gravel.
Drilled Wells Cable tools	Unconsolidated and consolidated medium hard and hard rock	Any depth	1500 2/	3-24 in.	Steel or wrought iron pipe	All uses	3-3000	Effective for water exploration. Requires casing in loose materials. Mud-scow and hollow rod bits developed for drilling unconsolidated fine to medium sediments.
Hydraulic rotary	Silt, sand, gravel less than 1 inch; soft to hard consolidated rock.	Any depth	1500 2/	3-18 in.	Steel or wrought iron pipe	All uses	3-3000	Fastest method for all except hardest rock. Casing usually not required during drilling. Effective for gravel envelope wells.
Reverse hydraulic rotary	Silt, sand, gravel, cobble	5 - 100	200	16-48 in.	Steel or wrought iron pipe	Irrigation, industrial, municipal	500-4000	Effective for large diameter holes in unconsolidated and partially consolidated deposits. Requires large volume of water for drilling. Effective for gravel envelope wells.
Air rotary	Silt, sand, gravel less than 2 inch, soft to hard consolidated rock	Any depth	2000 2/	12-20 in.	Steel or wrought iron pipe	Irrigation, industrial, municipal	500-3000	Now used in oil exploration. Very fast drilling. Combines rotary and percussion methods (air drilling) cuttings removed by air. Would be economical for deep water wells.
Augering Hand auger	Clay, silt, sand, gravel less than 1 inch	5 - 30	35	2-8 in.	Sheet metal	Domestic drainage	3 - 50	Most effective for penetrating and removing clay. Limited by gravel over 1 inch. Casing required if material is loose.
Power auger	Clay, silt, sand, gravel less than 2 inch	5 - 50	75	6-36 in.	Concrete, steel or wrought iron pipe	Domestic, irrigation, drainage	3-100	Limited by gravel over 2 inch, otherwise same as for hand auger.

1/ Yield influenced primarily by geology and availability of groundwater.
2/ Greater depths reached with heavier equipment.

Exhibit 12-2 Water well construction methods and applications



Example: The water stands 75 feet in a well and the pumping test yielded 1470 g.p.m with a drawdown of 23 feet. This is 30% of the total possible drawdown. The curve shows that at 30% of the maximum drawdown, the well will produce 52% of the maximum yield. 1470 g.p.m. is 52% so the maximum yield or 100% would be $\frac{1470}{.52}$ = 2827 g.p.m. The curve shows that 77% of the maximum capacity can be obtained with a 50% (38 feet) drawdown. 2827 x .77 = 2253 g.p.m. yield with a 38 foot drawdown.

From Bulletin 1238, Edward E. Johnson Inc. Revised 1955

Exhibit 12-3 Relation of drawdown to yield

Size of Cylinder (Inches)	Capacity Per Hour (Gallons) 1/		Elevation in Feet to Which Water Can Be Raised					
			Size of Mill					
	6'	8' - 16'	6'	8'	10'	12'	14'	16'
1-3/4	105	150	130	185	280	420	600	1000
1-7/8	125	180	120	175	260	390	560	920
2	130	190	95	140	215	320	460	750
2-1/4	180	260	77	112	170	250	360	590
2-1/2	225	325	65	94	140	210	300	490
2-3/4	265	385	56	80	120	180	260	425
3	320	470	47	68	100	155	220	360
3-1/4	...	550	...	...	88	130	185	305
3-1/2	440	640	35	50	76	115	160	265
3-3/4	...	730	...	...	65	98	143	230
4	570	830	27	39	58	86	125	200
4-1/4	...	940	...	...	51	76	110	180
4-1/2	725	1050	21	30	46	68	98	160
4-3/4	...	1170	...	...	...	61	88	140

1/ The pumping capacity of the mills in the table varying in diameter from 8 to 16 feet is the same with cylinders of the same diameter.

Exhibit 12-4 Pumping capacity of mills

ENGINEERING FIELD MANUAL

CHAPTER 13. DIKES AND LEVEES - WILDLIFE WETLAND DEVELOPMENT

Compiled by: H. J. Foreman, Drainage Engineer, SCS, Fort Worth, Texas

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ENGINEERING FIELD MANUAL

CHAPTER 13. DIKES AND LEVEES - WILDLIFE WETLAND DEVELOPMENT

PART I - DIKES AND LEVEES

1. GENERAL

DEFINITION

Dikes and levees are embankments of earth or other suitable materials constructed to protect land against overflows from lakes, streams and tides, and to protect flatland areas from spreading surface waters.

INTRODUCTION

The following guidelines and procedures apply generally to the planning, design, and construction of all classes of dikes and levees but to class III dikes and levees in particular. Both dikes and levees will be referred to as dikes.

Class III dikes are embankments which protect agricultural lands of relatively low capability or improvements of relatively low value. These dikes are limited to low heads of water. The maximum design water stage above the normal ground level, exclusive of crossings at channels, sloughs, swales and gullies, is:

1. For mineral soils, 6 feet
2. For organic soils, 4 feet

2. INVESTIGATIONS

DIKE LOCATION

Class III dikes often parallel a drainage ditch, but they may cross the lower end of a drainage system or completely surround an area to be protected.

Tentative locations can be made on aerial photographs or overlays for technical and rough cost comparisons.

Preliminary Investigation

It will be necessary to make a preliminary determination of the dike location in order to establish the:

1. Expected flood stages (height and duration).

2. Elevations of the land to be protected.
3. Property ownerships involved.
4. Physical problems likely to be encountered, especially soil conditions as they relate to foundation and fill requirements.
5. Land use and the improvements on the land, in order to evaluate the economic importance of the area to be protected.

Detailed Investigation

When making a detailed investigation of the dike location it is desirable to:

1. Locate the dike on soils that will provide the best foundation conditions and embankment materials.
2. Use the most economical length that will protect the largest usable area.
3. Avoid, when possible, hazards such as sloughs, swamps, sharp eroding bends in watercourses, or direct exposure to long reaches of open water.
4. Make use of all natural protection against waves, such as dense stands of trees, reeds, or brush.
5. Parallel, where possible, public roads or property lines to reduce access and easement problems.
6. Avoid reducing the width of natural floodways to the extent that it would adversely affect the cost and safety of the dike or cause increased flood stages on unprotected lands.
7. Coordinate the location of the dike with units of the drainage system in the area to be protected.
8. Include a natural storage basin within the protected area to reduce gravity drainage structure or pump capacities.

HIGH WATER DETERMINATION

The first step after the tentative location has been made is to determine the height, frequency and duration of floodwater or storm tide stages.

High stages along coastal areas usually result when high daily tides are increased by high winds and waves. High wind tides can be expected several times annually in some areas. Hurricane winds along the Atlantic and Gulf Coasts sometimes cause high water stages along the shorelines of freshwater lakes in the region. These also should be considered in design.

Records of flood stages and dates generally are available from the Corps of Engineers, Coast Guard Stations, municipal and port authorities, and the Coast and Geodetic Survey of the U. S. Department of Commerce. The latter issues annual editions of "Tide Tables - East Coast" and "Tide Tables - West Coast." Localized information may be obtained from landowners, recreational groups or other sources.

The duration of storm tides resulting from hurricanes can, in the absence of records, be assumed to be about 75 hours along the southern and eastern coasts. However, actual records should be used where available and authentic.

Flood data on large streams can be obtained from the U. S. Geological Survey, other federal agencies, and certain state agencies. Data on small streams may be available from local community records, newspapers, and landowners. The latter data usually is in the form of high-water marks.

Where information on flood stages of streams is not available, computations based on the hydrologic conditions of the watershed and selected rainfall conditions and frequency can be made to obtain an approximate runoff. From this, an estimate of the flood stage can be made. Procedures for determining runoff are given in Chapter 2 of this manual.

Where dikes restrict flow in floodways, it is especially important to determine the stage for the design discharge. If the flood plain on one side of a stream is to be protected by a dike, it will be necessary to find if inundation of the unprotected land will be increased in depth, duration and extent. If so, and the land is in other ownership, legal complications could arise unless State regulations or water laws are complied with.

DIKE FOUNDATION

The foundation investigation should be made in sufficient detail to determine if the site is suitable for the construction of a dike.

Soil borings are necessary for all dikes. Where a soil survey of the area is available, it may be used as a guide to the location of borings. Where no soil survey is available for the preliminary analysis, boring locations should be based on site appearance and the findings as the boring process continues.

In some instances it may be desirable to open a pit for a close study of the substrata. Borings or pits should reveal:

1. The elevation of the water table.
2. Thickness, classification and position of each soil layer.
3. The existence of any foreign materials, such as shell deposits.

The borings should be made to a depth at least equal to the difference between the channel bottom and the design water surface. The locations of highly permeable soil layers should be known to determine their influence on piping and added pumping costs, and the relationship of the dike location to the location of interior drainage facilities. Probings through soft materials may supplement borings to establish an accurate profile of firm foundation material.

EMBANKMENT MATERIALS

Dikes usually are constructed of fill material borrowed adjacent and parallel to the line of the dike. In cases where borrow will parallel the dike location, investigations for foundation and borrow can be combined. It may be necessary, in the case of some dikes, to open specific borrow pits outside the immediate area and transport good fill material to the site. Where unstable soil conditions are found, it may be more economical to change the dike location rather than employ the costly construction methods required by such unstable soils.

For preliminary investigations, Figure 13-1, Soil characteristics, will assist in evaluating soil conditions along the line of the dike and can be used as a guide to soil stability and permeability.

Simple field tests frequently provide sufficient information on the stability of fill materials. Such tests can be made in accordance with field procedures outlined in Chapter 4 of this manual.

3. DESIGN OF THE DIKE

Dikes may fail by overtopping, undermining, sloughing, piping, or by seepage along drainage structures placed through the dike. The design of the dike should eliminate these dangers as much as possible. Since dikes usually are long, and differences in soil conditions normally exist along the route, adjustments may be needed in the design section and construction methods for the different soil conditions.

Freeboard is provided to insure against overtopping of the dike by the design flood. Locating the dike away from the channel so that it will not be scoured by high velocities will insure against undercutting. The sloughing of the dike can be reduced by using proper side slopes and construction methods. The seepage line along culverts or discharge pipes should be increased by 15 percent or more with antiseep collars. When drainage pumps are installed, the pump discharge pipe should be located over the top of the dike. If it is placed through the dike, the pipe should be placed above the design water surface and the connection between it and the pump made with a flexible coupling to reduce vibration.

In the design of fills consideration should be given to the possible moisture conditions in the soil at the time the fill is to be placed. Plastic soils, if placed dry, may become unstable when wet. Dikes on soft foundations may require a considerable amount of maintenance to keep the settled fill up to required height. Nonplastic soils or those low in plasticity, if placed when wet, may slump excessively. Soils with low plasticity may need to be raised in lifts. Soils with a high organic content will shrink due to oxidation. Consolidation also will be high in organic soils.

	Group Symbol	Soil Description	Suitability for Class III Dikes	Permeability and Slopes
Coarse-grained soils - (Less than 50% passing #200 sieve)	GW	Well graded gravels and gravel-sand mixtures. Little or no fines.	Very stable - suited for shell of dike. Good foundation bearing.	Rapid - will need core.
	GP	Poorly graded gravels and gravel-sand mixtures. Little or no fines.	Stable - suitable for shell of dike. Good foundation bearing.	Rapid - may not need core for lower stages of short duration.
	GM	Silty gravels and gravel-sand-silt mixtures.	Stable - generally adequate for all stages. Good foundation bearing. Good compaction with rubber tires.	Moderate - may not need core except for long flood duration.
	GC	Clayey gravels and gravel-sand clay mixtures.	Stable - adequate for all stages. Good foundation bearing. Good compaction with rubber tires.	Slow permeability.
	SW	Well graded sands and gravelly sands. Little or no fines.	Very stable - adequate for class III dikes. Good foundation bearing. Compaction can be done with crawler tractor.	Rapid - may need core for higher stages of long duration.
	SP	Poorly graded sands and gravelly sands. Little or no fines.	Stable - adequate for class III dikes. Generally fair foundation bearing. Use flat slopes and wide berms. Compaction can be done with crawler tractor.	Rapid - will need core for long duration. Use flatter slopes. Protect against wave action.
	SM	Silty sands and sand-silt mixtures.	Fairly stable - adequate for low stages. Only fair foundation bearing. Use wide berms. Good compaction with rubber tires.	Moderate - Use flat slope on wet side. Protect against wave action
	SC	Clayey sands and sand-clay mixtures.	Stable - adequate for all stages. Generally good foundation bearing. Fair compaction with rubber tires.	Slow permeability.

Figure 13-1.--Soil characteristics - for use in preliminary investigation (Based on Unified Soil Classification System and Field Procedure)

Sheet 1 of 2

	Group Symbol	Soil Description	Suitability for Class III Dikes	Permeability and Slopes
Fine-grained soils - (More than 50% passing #200 sieve)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands and clayey silts of slight plasticity.	Low stability - generally adequate for low stages. Fair foundation bearing. Dumped fill should be used on Class III only. Fair compaction with rubber tires.	Moderate - use flat slope on wet side. Protect slopes against all erosion forces.
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays and lean clays.	Stable - adequate for all stages. Fair foundation bearing. Fair compaction with rubber tires. Use dumped fill on lower stages only.	Slow permeability.
	OL	Organic silts and organic clays having low plasticity.	Very low stability - may be adequate for Class III dikes of low height. Can use dumped fill.	Moderate - use for very low stage only. Slopes at natural angle of repose when wet.
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils and elastic silts.	Low stability - generally adequate for all stages. Difficult to compact. Could use dumped fill for low stages. Poor foundation bearing.	Slow permeability. Use flat slopes and protect against erosion.
	CH	Inorganic clays having high plasticity and fat clays.	Fairly stable - adequate for all stages. Poor compaction, dumped fill may be adequate.	Very slow permeability. Use flat slopes on wet side.
	OH	Organic clays having medium to high plasticity and organic silts.	Very low stability - adequate only for low stages and can use dumped fill. Has poor foundation bearing and compaction.	Very slow - use for low stages only. Use flat slopes.
	Pt	Peat and other highly organic soils.	Very low stability - use only for temporary dikes. Remove from foundation for mineral soil dikes.	Variable - may vary significantly between vertical and horizontal.

Figure 13-1.--Soil characteristics - for use in preliminary investigation (continued)

Note: Rubber tires refer to equipment for shaping.

Sheet 2 of 2

Where design water stages are of long duration and heavy waves are expected, or where rapid lowering of the stage is possible, flatter side slopes and special protection for the waterside of the dike may be required. This special protection is important where the fill is of slightly plastic or noncohesive soils.

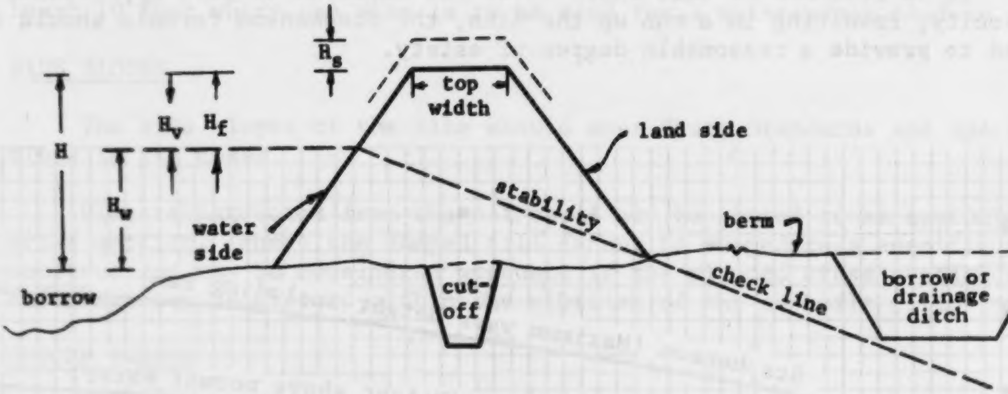


Figure 13-2 Section through dike

The design height of the dike (H) will be the sum of the design high water stage (H_w), the added height (H_v) for wave action, if any, and the freeboard (H_f). The constructed height will include an allowance for settlement (H_s), which will depend on the foundation and material used in construction. The actual design high water stage should be based on the water surface profile.

Freeboard (H_f) is the allowance added to the selected flood stage with or without the inclusion of wave heights. Freeboard for dikes should be a minimum of 2.0 feet, or, where wave action is expected, it should be 1.0 foot plus the computed wave height.

Wave height allowances should be based on the best local experiences or computed by an acceptable formula. The Stephenson formula with the Gaillard modification may be used in computing wave heights for open water reaches not to exceed 10 miles and winds not to exceed 60 miles per hour.

The basic Stephenson formula, which results in wave heights shown in Figure 13-3, is as follows:

$$\text{Wave height, } H_v, = (1.5\sqrt{f}) + (2.5 - \sqrt[4]{f})$$

Where: H_v = Wave height, trough to crest
f = Fetch, open water, in nautical miles (6076 feet)

To convert (H_v) to a wave height above normal water surface, Gaillard suggests that (H_v) be modified as follows:

Modified wave height = $H_v \times 0.75$

See Figure 13-3 for a comparison of results

It is recommended that where waves are expected to have appreciable velocity, resulting in a run up the dike, the Stephenson formula should be used to provide a reasonable degree of safety.

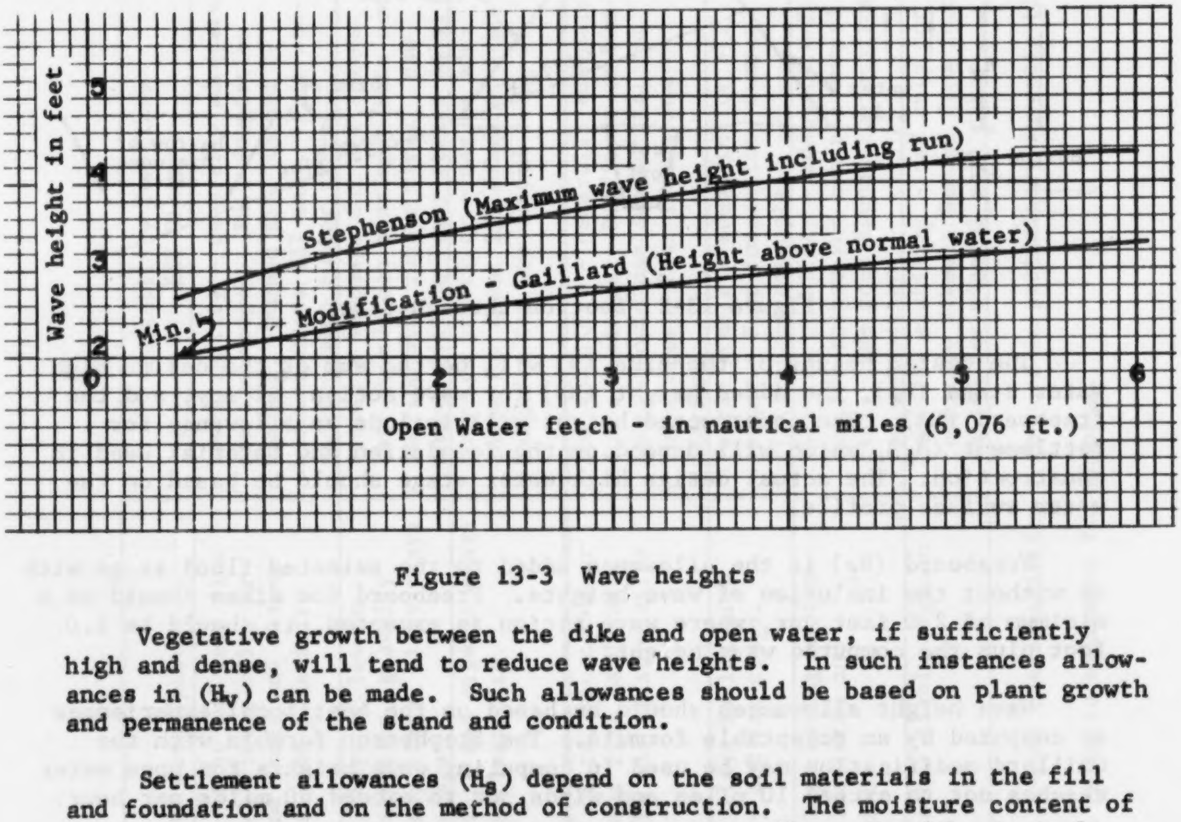


Figure 13-3 Wave heights

Vegetative growth between the dike and open water, if sufficiently high and dense, will tend to reduce wave heights. In such instances allowances in (H_v) can be made. Such allowances should be based on plant growth and permanence of the stand and condition.

Settlement allowances (H_s) depend on the soil materials in the fill and foundation and on the method of construction. The moisture content of the soil during construction also is important. Where the dike is to be compacted by construction equipment operating over the area, a settlement allowance of not less than 5 percent of the fill height should be included. Where a fill is dumped and shaped, an allowance of not less than 10 percent of the height of the dike is suggested. When a dragline is used in constructing the dike an allowance of at least 20 percent of the height of the fill is recommended. Actual allowances will be governed by the kind of soil material to be used and the moisture content anticipated. For soils exceptionally high in organic matter, the settlement allowance should be no less than 40 percent since they likely will be placed in a near-saturated condition.

TOP WIDTH

A minimum top width of 6 feet may be planned for mineral soil dikes designed to control depths of water of 6 feet or less. When more than 6 feet of water is designed for, such as short sections across sloughs, streams and gullies, the minimum top width should be 8 feet. A minimum top width of 8 feet is used in organic soils. Top widths should be at least 10 feet where the dike is to be used for a maintenance roadway.

SIDE SLOPES

The side slopes of the dike should meet State Standards and Specifications in all cases.

Dikes constructed from channel spoil may be shaped to an approximate cross section. Where the dumped fill cannot be shaped to a specific slope, construction may be considered adequate if the planned cross section plus shrinkage can be plotted within the plotting of the as-built fill.

CUTOFF TRENCH

When the dike foundation has layers of permeable soil or layers creating a piping hazard a foundation cutoff or core trench should be installed. The cutoff trench should be of sufficient depth and width to minimize the hazard. The width should be adequate to provide working space for placing and compacting equipment.

EMBANKMENT STABILITY

Subsurface drains should not be installed or permitted to remain, without protection, closer to the landside toe of a dike than a distance 3 times the design water height for the dike. If subsurface drains are to be installed or remain closer than this distance, they should be enclosed in a graded sand-gravel filter, as for a toe drain. Closed pipe within the specified distances from the dike may be laid instead of a drain and filter.

Where a dike crosses an old channel, the base of the dike should be widened on the landside. The additional width should be at least equal to the height of the dike above normal ground elevation. The top of the extended base should be no less than 1.0 foot above normal ground and should slope away from the dike to provide for the runoff from the dike. The side slope of the extended fill should be no steeper than the landside slope of the dike. Such an extension of the base of a dike is known in certain areas as a "banquette." See Figure 13-4.

Where highly permeable soil is used in the dike fill, especially over a more slowly permeable foundation, the landside base of the dike may need to be extended. The additional width may be provided in the manner shown in Figure 13-5 to increase the stability of the dike.

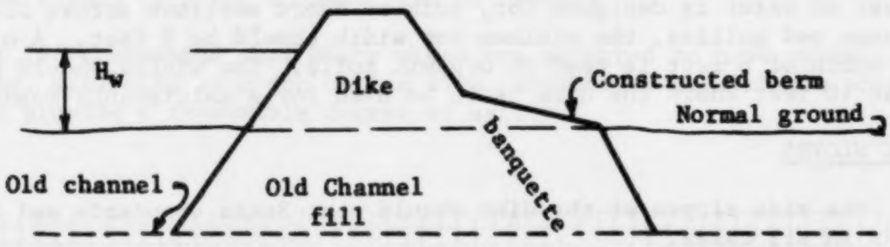
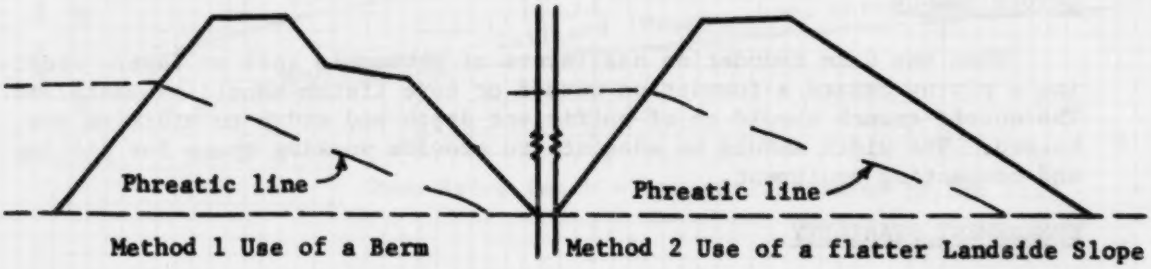

H_w
Dike
Constructed berm
Normal ground
banquette
Old channel
Old Channel fill

Figure 13-4 Use of a banquette at a channel crossing


Phreatic line
Phreatic line

Method 1 Use of a Berm | Method 2 Use of a flatter Landside Slope

Figure 13-5 Methods of increasing the stability of a dike

BERMS

If borrow (borrow ditch or channel) is excavated parallel to the line of the dike, the berm which separates the dike from the borrow should be wide enough to effectively protect the toe of the dike.

The minimum width of berm for a class III dike should be as shown in Table 13-1.

Table 13-1 Minimum berm width

Depth of water	Minimum berm width
Less than 6 ft.	10 ft.
Over 6 ft. (for short sections)	15 ft.
Organic soil	25 ft.

When the foundation materials are noncohesive or highly permeable, the width of the landside berm should be equal to 2.5 times the water depth. This is necessary to prevent piping on the face of the interior channel. Such piping could cause the channel bank and the berm to erode and slump, thereby undermining the dike.

For dikes where the design water depth is more than 6 feet for short sections, the landside ditch or borrow pit should be far enough away from the dike to insure stability. A line drawn from the design waterline on the face of the dike through the landside toe of the dike should, when extended, pass below the ditch or borrow pit cross section. See Figure 13-2.

If a dike has a narrow top width, the landside berm should be wide enough to accommodate a maintenance roadway during critical high water periods. This facilitates travel to all sections where no road exists on the dike.

4. CONSTRUCTION

The foundation area of all dikes should be cleared of trees, stumps, logs, roots, brush, boulders, or organic matter which would interfere with the scarifying of the area. All channel banks and sharp breaks should be sloped no steeper than 1:1. Organic soils should be removed from the foundation area, except where the dike will be constructed from organic soil. For dikes constructed in organic soils the top 2 feet of the borrow area should be placed at both toes of the embankment to retain the soft material placed in the fill.

A cutoff trench, if planned, should be excavated approximately along the centerline of the dike. This excavation usually is done by a dragline, although other types of equipment can be used. The trench should be backfilled with the least permeable soil available and compacted. The excavated material, if suitable, may be used in the fill.

Where the dike crosses old channels the soft, unsuitable material should be removed from the base section. The bank of the old channel should be sloped no steeper than 1:1 before placing the new fill.

Class III dikes are often constructed from spoil excavated from drainage ditches. The spoil is placed to the required height and shaped. If the spoil is wet, several months may be required for draining and drying before shaping can be done. Where additional stability or compaction is needed, the dike should be constructed in stages.

Generally, the borrow is taken from the waterside of the dike. Ditches are sometimes overexcavated to obtain additional fill material. At times it is necessary to obtain fill from the landside, especially when it eliminates excavating through highly permeable strata on the waterside, which could result in excessive seepage through and under the dike during flood stages.

A borrow ditch on the landside may be planned as a unit of the interior drainage system and the excavated material used in the dike. Such a ditch should be far enough away from the dike to eliminate undermining.

Physical features, such as roads, railroads, swamps and lack of suitable material may require that the borrow be transported from a distant point.

A borrow ditch located along the waterside should be interrupted at intervals to slow the velocity of the water moving along the toe of the fill. Such unexcavated plugs also serve as crossovers for maintenance equipment at low water stages. They should be spaced at intervals not to exceed 1320 feet and should be at least 25 feet wide.

CONDUITS

Any conduit through a dike should be placed on a firm foundation. Selected backfill material should be placed in 6- to 8-inch layers around the conduit and each layer thoroughly compacted. The conduit itself should be free from leakage due to internal pressures. Antiseep collars should be used as an added precaution against seepage along the surface of the conduit.

DIKE PROTECTION

Any dike exposed to open water may, at times, be subject to the destructive action of waves. The most widely used protective measures to safeguard such dikes include:

1. Heavy sod cover.
2. Flat front slopes.
3. Extra top width.
4. Location of the dike behind a wide foreshore, 100 feet or more in width, on which adapted wave-obstructing vegetation can be established.

Method 4 is the most desirable method of dissipating waves before they reach the dike. Bush or brushy vegetation is best suited for counteracting wave action. This type of protective vegetation should be established beyond the borrow ditch and not on the berm. Riprap for protection of Class III dikes is generally not feasible except for short sections. If it is required, see Chapter 17 of this manual.

An adequate protective cover of grasses should be established on all exposed surfaces of the dike where it is necessary to protect against erosion by flood flows or wave action, or from rainfall and runoff on the dike. The seedbed preparation, seeding, fertilizing, mulching, and fencing should comply with the local Technical Guides.

5. MAINTENANCE

The dike should be patrolled periodically and especially after severe storms. Conduits through the dike should be thoroughly inspected as they are possible points of failure. Any weakness should be repaired immediately for the dike to continue to be effective.

A good sod cover over the dike can prevent erosion rills and reduce the maintenance required. Mowing or controlled grazing by cattle is desirable when the slopes are 3:1 or flatter. Grazing should be rigidly controlled to prevent damage to the sod cover.

Trees and brushy growth should not be permitted to remain on the dike. Where rodent damage is a problem, measures should be taken to discourage them from burrowing into dikes. Hogs should not be allowed on the dikes. Occasional spraying of brushy growth with herbicides will assist in the maintenance of a sod cover.

Where a sand layer exists under the dike, a heavy inflow of seepage may be expected during periods of high flood or tide stages. Pumps installed at such locations to provide interior drainage should be regulated to keep the elevation of the water in the interior ditches as high as possible during such periods. By keeping the difference in elevation between the outside and the inside water to a minimum, the tendency for seepage water and sand to flow into the drainage ditches, the possibility of bank sloughing, the loss of capacity in the drainage system, and the possibility of dike failure will be reduced.

PART II - WILDLIFE WETLAND DEVELOPMENT

1. GENERAL

DEFINITION

Wildlife wetland development consists of creating or improving a wetland habitat for wildlife by diking, ditching, planting, or other means.

INTRODUCTION

Wetlands are developed to provide food and water for wild ducks, crayfish, snipe, and other wildlife by the development of new habitat, or the improvement of existing habitat in predominantly rural or agricultural areas.

This practice is applicable to areas that have:

1. Soils that will retain water without excessive seepage losses.
2. Soils suitable for construction of embankments.
3. An adequate surface or subsurface water supply, except that runoff from rainfall may be the only water source when recommended by an SCS biologist and engineer.

An adequate water supply is defined as that which will normally provide complete flooding of the development area within one month after the structure or gates are closed.

2. DESIGN

DESIGN CRITERIA

The average water depth, measured from normal ground when the impoundment is flooded, should not exceed 3 feet. Design dike heights should not exceed 6 feet, except where greater heights are necessary to cross narrow depressions.

MARSHLANDS

Soils

Wildlife developments are adapted to most soils but normally are recommended on soils with land capability classes IV and VII. Developments may be constructed on class VIII soils if a "Marsh Evaluation Study" is conducted and the determination made that the site is feasible for construction.

Soil borings and probes may be used to determine the depth of organic material, the suitability of the soil for embankment construction, and suitability for structure and embankment foundation. Ordinarily, embankments cannot be constructed in one lift where organic material exceeds 2 feet in depth.

If it becomes necessary to construct a dike on organic material deeper than 2 feet, suitable mineral earth materials should be hauled in to construct the dike; or the landowner should be advised of the need for, and agree to, a construction period during which the dike would be constructed in several stages.

Some organic soils have a steep natural slump that cannot be shaped to the planned side slopes. In such cases the dike should be built to the designed base width and the top widened to meet the steeper side slopes.

Cutoff Trench

A cutoff trench may or may not be required, depending upon foundation conditions. Where needed, it should be designed to penetrate impervious material and be wide enough to accommodate the construction equipment.

Embankment

The minimum dimensions recommended for embankments to be constructed in marshlands are shown in Table 13-2.

Table 13-2 Minimum embankment dimensions for marshlands

Settled Height (feet)	Minimum					
	Top Width (feet)	Bottom Width (feet)	Side Slope (feet)	Free-board (feet)	Berm (feet)	Allowance for Settlement (Percent)
2.5	4	1/	2½:1	0.5	10	30
2.6 - 6.0	6	1/	2½:1	1.0	15	30

1/ Dikes built on soils that do not permit proper shaping should have a base width equal to 5 times the settled height, plus the planned top width.

Where wave action may cause excessive erosion of the fill, the top may be widened; or the freeboard may be increased in height to take care of expected wave action that might cause overtopping of the fill.

Emergency Spillway

An emergency spillway is not required where the impoundment is entirely surrounded by a dike and has no runoff discharging into it.

Where there is a contributing drainage area to the impoundment, emergency spillway capacity should be sufficient to carry the maximum outflow expected for a rainfall frequency of once in 10 years. Reduction of spillway size due to temporary detention may be considered.

The emergency spillway may consist of a concrete or vegetated earthen spillway, a conduit (pipe), or a combination of a concrete or vegetated spillway and a conduit.

If a vegetated spillway is used, the crest of the spillway should be at least 0.2 foot above the normal reservoir water elevation maintained by the water control structure.

Water Control Structures

Structures should be provided that will automatically draw down the temporarily stored water to the planned surface elevation in the impoundment at an average rate of not less than 0.5 inch of runoff from the watershed in 24 hours.

The type of structure used may be:

1. A straight drop structure of treated timber, metal, or concrete equipped with removal stoplogs.
2. A steel pipe provided with a swivel elbow and riser.
3. A metal drop inlet structure equipped with a gate or plug for controlling flow.
4. A drop inlet structure equipped with stoplogs to control outflow and surface elevation. (See Chapter 6 of this manual.)

Design

The rate of water removal, water elevations to maintain, amount of fluctuation to design for, and structural design requirements are contained in appropriate State Standards and Specifications. Other design criteria and charts or tables are given in Chapter 6 of this manual.

Water Salinity

Salt water may be used to flood marshlands to the extent needed to provide proper salinity.

OTHER LANDS (EXCLUDING MARSHLANDS)

Water Supply

Unless it has been determined that railfall runoff will supply sufficient water for wildlife development, provisions should be made for pumping from a surface or underground source or for using gravity flow from a stream or storage reservoir.

Cutoff Trench

When specified in the plans, a cutoff trench should be excavated deep enough to penetrate impervious material and wide enough to accommodate construction equipment.

Embankments

The minimum dimensions recommended for embankments constructed in other than marshlands are shown in Table 13-3.

Table 13-3 Recommended minimum embankment dimensions for other than marshlands

Settled Height (feet)	Minimum Top Width (feet)	 Bottom Width (feet)	 Side Slope (feet)	 Free-board (feet)	 Berm 1/ (feet)	Allowance for Settlement (Percent)
Less than 0.75	0	4.0	3:1	0.4	0	**Dragline** Clays and silts - 30 Sandy soils - 20 **Dozer, grader, scraper** Clays and silts - 20 Sandy soils - 10
0.75 to 1.0 (Above heights based on vertical interval plus designed depth of water against dike plus 0.4 foot)	0	6.0	3:1	0.4	0	
1.1 to 3.0						
No outside drainage area	4.0	As calculated	3:1 and 2:1	0.75	4.0	
With outside drainage area	4.0		3:1 and 2:1	0.3 above spillway design flow	4.0	
3.1 to 6.0						
No outside drainage area	6.0	As calculated	3:1 and 2:1	1.0	6.0	
With outside drainage area	6.0		3:1 and 2:1	1.0 above spillway design flow	6.0	

1/ Not required for bulldozer construction if side slope of upstream borrow is not steeper than front slope of embankment.

Water Control Structures

Where levees are greater than one foot in height, a wooden, metal, or concrete structure should be provided to automatically remove excess runoff and maintain the normal water surface elevation during periods when the wildlife area impoundment is flooded. See Chapter 6 of this manual for typical water control structures.

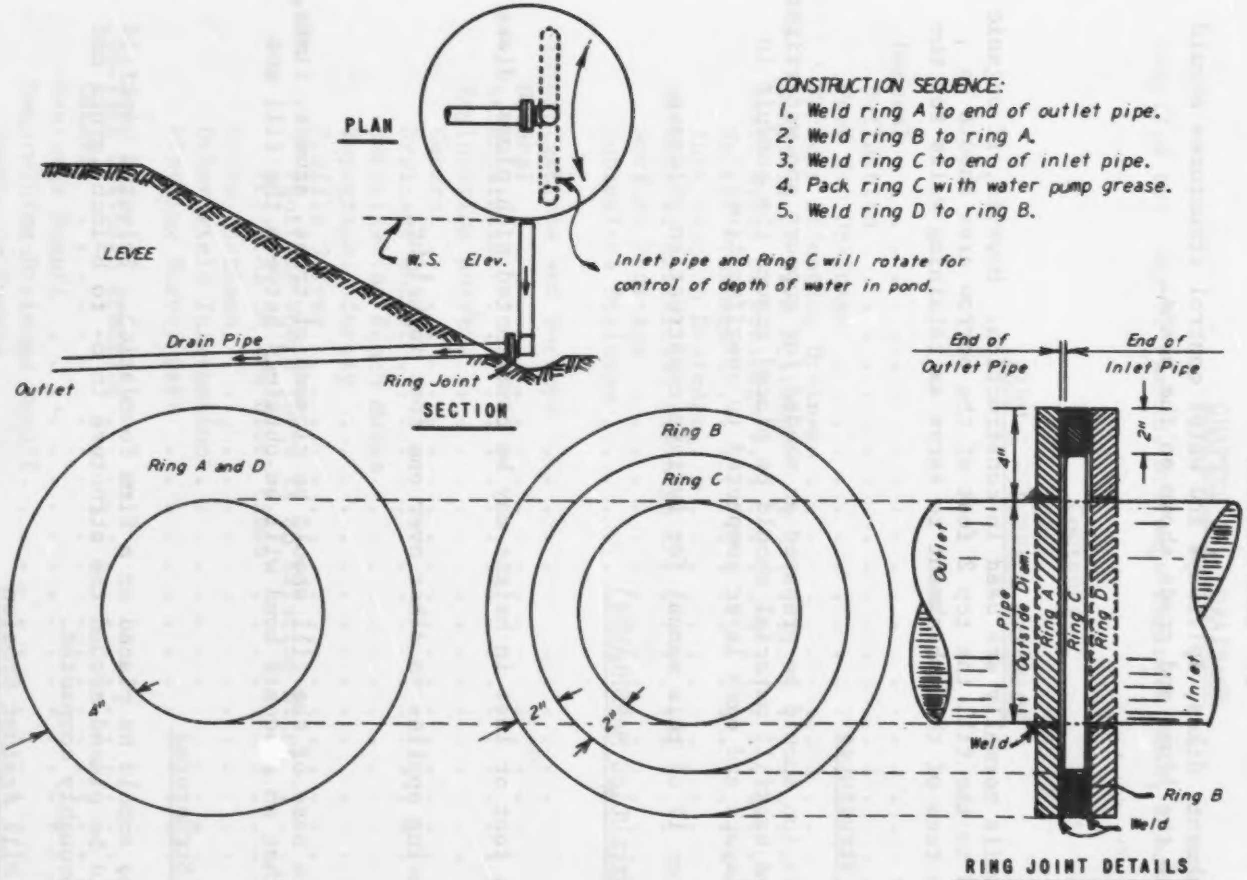
Such structures are not required for impoundments with dikes one foot or less in settled height. Vegetated spillways may be used in lieu of wood, metal or concrete structures, and dewatering may be done by cutting the dikes.

Water control structures may consist of one of the following:

1. A straight drop structure equipped with removable stoplogs.
2. A pipe drop inlet with a gate or stoplogs for control.
3. A steel pipe provided with a swivel elbow and riser installed so that the top of the riser will be at the normal water elevation when fastened in a vertical position, and which will empty the impoundment when lowered to a horizontal position. Figure 13-6 is a working drawing of a swivel elbow and riser.

Design

The rate of water removal, water elevations to maintain, amount of fluctuation to design for, and structural design requirements are contained in appropriate State Standards and Specifications. Other design criteria and charts or tables are given in Chapter 6 of this manual.


PLAN
LEVEE
W.S. Elev.
Inlet pipe and Ring C will rotate for control of depth of water in pond.
Drain Pipe
Outlet
Ring Joint
SECTION
Ring A and D
4"
Ring B
Ring C
2"
2"
End of Outlet Pipe
End of Inlet Pipe
4"
2"
Outlet
Pipe
Outside Diam.
Ring A
Ring C
Ring D
Inlet
Weld
Ring B
Weld
RING JOINT DETAILS

CONSTRUCTION SEQUENCE:

1. Weld ring A to end of outlet pipe.
2. Weld ring B to ring A.
3. Weld ring C to end of inlet pipe.
4. Pack ring C with water pump grease.
5. Weld ring D to ring B.

NOTES:

1. Thickness of material for rings will vary with size and weight of pipe installed.
2. Use post to hold riser in position.
3. An additional elbow on levee side of ring joint will permit riser to be lowered perpendicular to the levee.

Figure 13-6 **FISH POND-DRAIN PIPE RING JOINT**

USE WITH SHALLOW WATER DEPTHS
DRESSER COUPLING MAY BE
SUBSTITUTED FOR RING JOINT

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE
USDA-SCS-FORT WORTH, TEX. 1966

1-65 4-L-19694-6 of 7

3. CONSTRUCTION

The embankment, dikes, spillways and water control structures should be installed to the lines and grade shown on the plans.

MARSHLANDS

Embankments

Mineral soils normally are used in construction. However, if organic soils are used in the fill the top 2 feet of the borrow area should be placed at both toes of the embankment to serve as retaining walls for the wet materials.

Water Control Structures

The foundation should be prepared as needed for support and watertightness. Selected backfill material should be placed around the conduit in 6- to 8-inch layers and each layer compacted to specifications.

See Chapter 17 of this manual for further construction guidance.

OTHER LANDS (EXCLUDING MARSHLANDS)

Embankments

Dikes one foot or less in height may be constructed with plows, disks or graders.

The following applies to dikes over one foot in height.

Foundation

The entire base of the fill should be cleaned of trees, stumps, limbs, and roots so that an adequate bond will be obtained between the fill and the base.

Water Control Structures

Structures should be placed on a firm foundation. Selected backfill material should be placed around the structure in 6- to 8-inch layers and each layer thoroughly compacted.

Protection of Fill Against Erosion

The entire outside slope and the inside slope above the planned waterline should be seeded or sodded to perennial vegetation.

ENGINEERING FIELD MANUAL

CHAPTER 14. DRAINAGE

Compiled by: Guy B. Fasken, Drainage Engineer, SCS, Lincoln, Nebraska

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ENGINEERING FIELD MANUAL

CHAPTER 14. DRAINAGE

PART I - SURFACE DRAINAGE

1. GENERAL

DEFINITION

Agricultural drainage is the removal of excess water from the land surface, or ground water from below the land surface to create more favorable conditions for plant growth. Surface drainage removes excess precipitation from the land surface at a rate which will prevent long periods of ponding or flooding without excessive erosion so that pasture, hay and cultivated crops will have the best possible moisture conditions. Subsurface drainage lowers the water table so that it will not interfere with root growth and development and promotes leaching to maintain the proper salt balance in the soil.

NEED FOR DRAINAGE

Visual evidences of inadequate drainage are surface wetness; lack of vegetation; undesirable vegetation such as marsh grass, sedge or swamp trees; crop stands of irregular color and growth; variation in soil color, salt deposits on the surface of the ground, etc. (Figures 14-1 and 14-2).

Agricultural drainage needs vary considerably because of differences in climate, geology, topography, soils, crops and farming methods. The drainage improvements needed should be determined for each particular site.

FACTORS AFFECTING DRAINAGE

The topography, geology, man-made obstructions, or soils of a site and its surrounding area, may result in conditions which block or retard water movement and cause poorly drained sites. Site factors can be placed in several categories. These may exist separately or in various combinations. The following are some of the more important site factors:

1. Lack of a natural drainageway or other depression to serve as an outlet. Such sites are common in glaciated and Coastal Plain areas where natural drainage systems are still in the process of development.

2. Lack of sufficient land slope to cause water to flow to an outlet. Such sites can be found in the irregular and pitted surfaces of glaciated land, above constrictions and natural barriers of valley flood plains, or above dams.

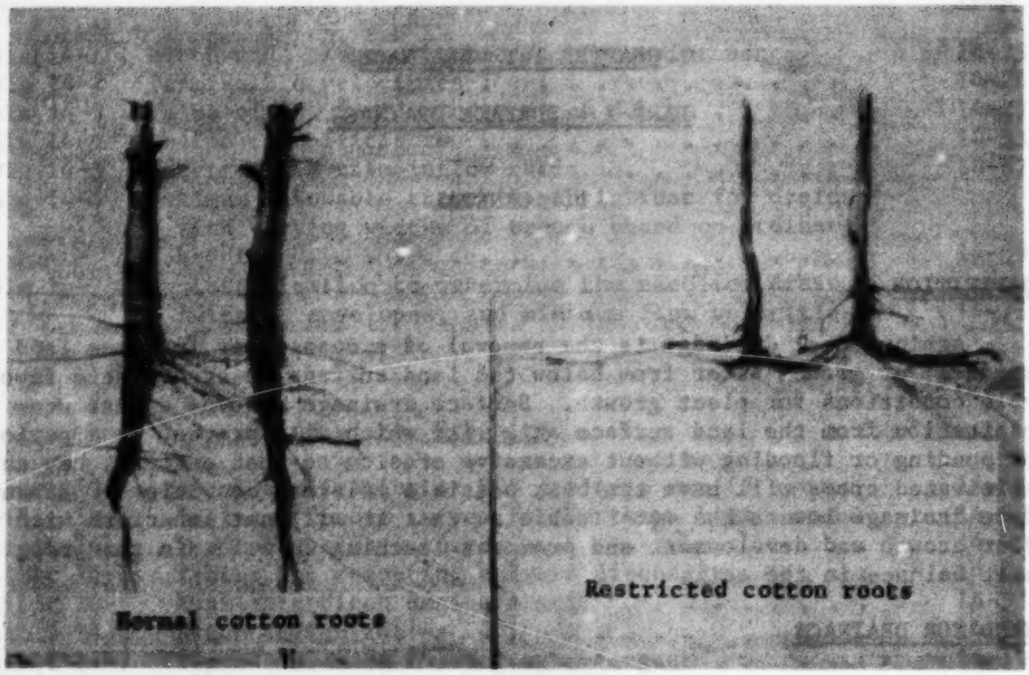

Normal cotton roots
Restricted cotton roots

Figure 14-1 Cotton roots showing the effect of poor drainage

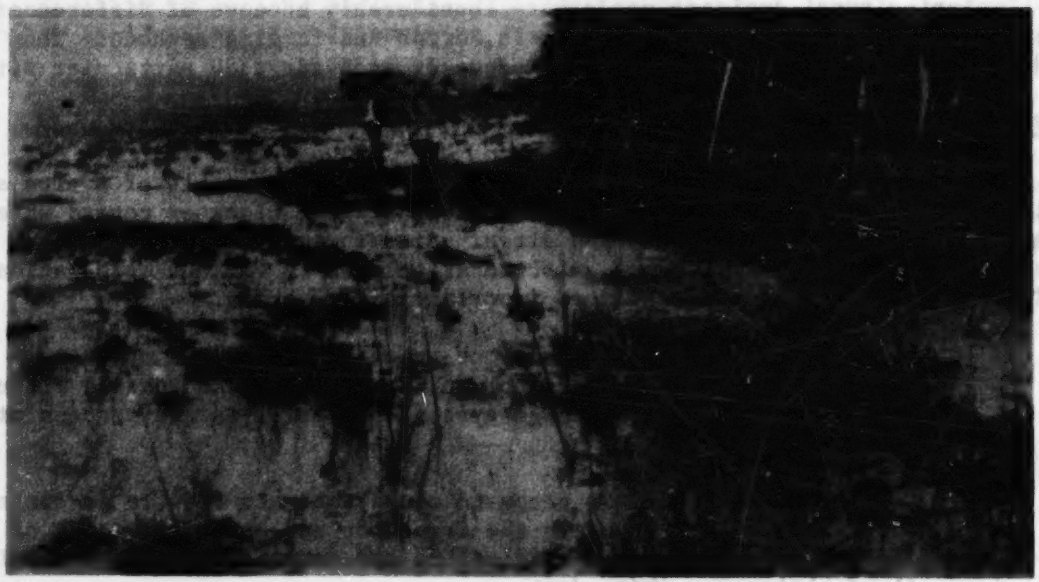


Figure 14-2 Portion of field needing drainage

3. Soil layers of low permeability that restrict the downward movement of water trapped in small surface depressions or absorbed in the soil profile. Many soils have a heavy subsoil, rock formation, or compact (hardpan) layer below the surface within the normal root zone of plants.

4. Man-made obstructions such as roads, fence rows, dams, dikes, and bridges and culverts with insufficient capacity and depth, which obstruct or limit the flow of water.

5. Natural surface barriers which cause local concentrations of water in sufficient amounts to aggravate the drainage problem.

6. Subsurface drainage problems in irrigated areas caused by deep percolation losses from irrigation and seepage losses from the system of canals and ditches serving the irrigated lands. Deep percolation losses from irrigation fall in the general range of 20 to 40 percent of the water applied. Seepage losses from canals and ditches vary widely and may be in the range of zero to 50 percent of the water applied.

   Most soils in arid areas contain some salts, varying in concentration, from slight to strong. High water table conditions caused by deep percolation from irrigation tend to concentrate salt accumulations in the root zone. One of the primary functions of subsurface drainage is to lower the water table and keep the level of salt concentration below the root zone area. Much of the subsurface drainage work in arid regions is actually salinity control.

There is no danger of overdrainage of most soils with poor internal drainage. Close spacing of drains on soils in poor physical condition aids in the establishment and growth of vegetation needed for soil conditioning even though this intensity of drainage may not be needed on the same soil in good physical condition. The removal of free water in the soil eliminates moisture in excess of that held by capillary action. Drainage does not remove the capillary water used by growing plants. The depth of the drains does control the height of the water table. If the water table is too low in soils with a low capillary "pull", moisture may not move upward into the root zone. This is a desirable condition in irrigated saline, saline-alkali, and alkali soils.

There is a possibility of overdraining some extremely sandy soils and some peat and muck areas. These soils have a particular depth of water table that is best for plant growth, which should be considered in designing the drainage system.

BENEFITS OF FARM DRAINAGE

Removal of free water promotes the soil bacterial action essential for the manufacture of plant food by allowing air to enter the soil. The roots of plants, as well as soil bacteria, must have oxygen. Drainage accomplishes this by providing air space in the soil. Rainfall water passing downward in the soil carries out carbon dioxide and permits fresh air to be drawn in. Thus, drainage provides needed soil aeration.

Surface drainage removes ponded water quickly, thereby allowing the remaining gravitational water to move through the soil.

The removal of free water by drainage allows the soil to warm up more quickly because more heat is required to raise the temperature of wet soil. Soil warmth promotes bacterial activity which increases the release of plant food and the growth of plants. Soils that warm up sooner in the spring can be planted earlier. Better germination conditions for seed are provided (Figures 14-3 and 14-4).

The removal of ground water improves the conditions for plant-root growth. For example, if free water is removed only from the top foot of soil, crop roots will feed in this confined area; but if free water is removed from the top 3 feet, this entire depth of soil is available as a root zone from which plants can obtain nutrients and moisture.

BASIC TYPES OF DRAINAGE

Drainage is accomplished by establishing or accelerating gravity flow within the site, by diverting flow from the site, or a combination of these two.

Relief Drainage

Establishing or accelerating excess waterflow within and from a site is referred to as relief drainage. Surface flows are removed by surface ditch systems and land grading. Subsurface flows are removed by relief drains. A relief drain is a lateral drain located parallel, or approximately so, to the flow of ground water.

Interception Drainage

Interception ditches or drains located across the flow of ground water (or seepage) are installed primarily for intercepting subsurface flow moving down a slope. While this type of drainage intercepts and diverts both surface and subsurface flows, the removal of surface water is generally referred to as diversion drainage and the removal of subsurface water by this method is referred to as interception drainage.

METHODS OF ARTIFICIAL DRAINAGE

Surface Drainage

Surface drainage involves removal of excess surface water by developing a slope to the free water surface. This may be accomplished by open ditches, and the shaping of the land surface when necessary, for the movement of such water to disposal ditches. Drainage by this method applies to flatland sites where:

1. Soils are slowly permeable throughout their profiles, such as slowly permeable clays, etc.

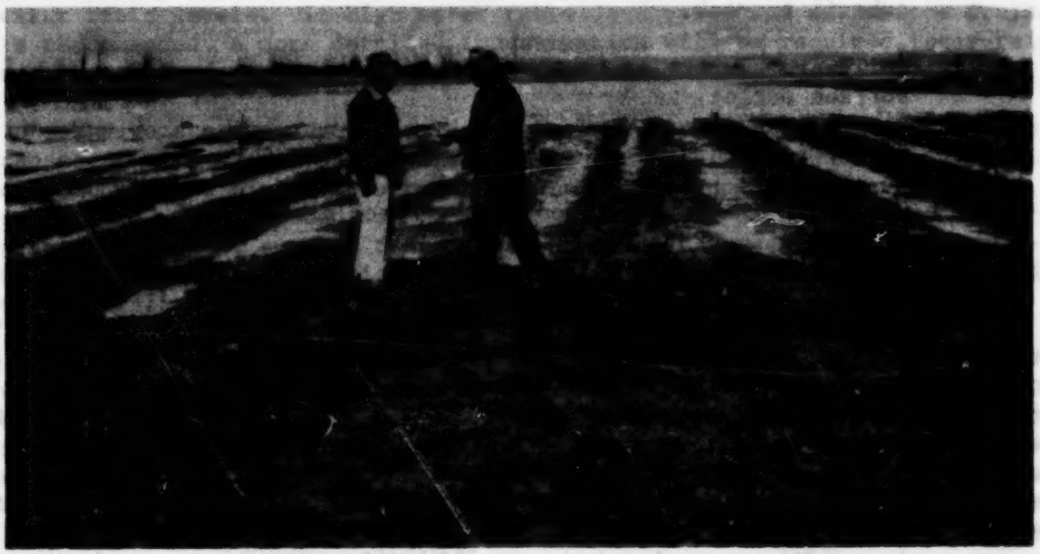


Figure 14-3 Field which is too wet for anything but late crops

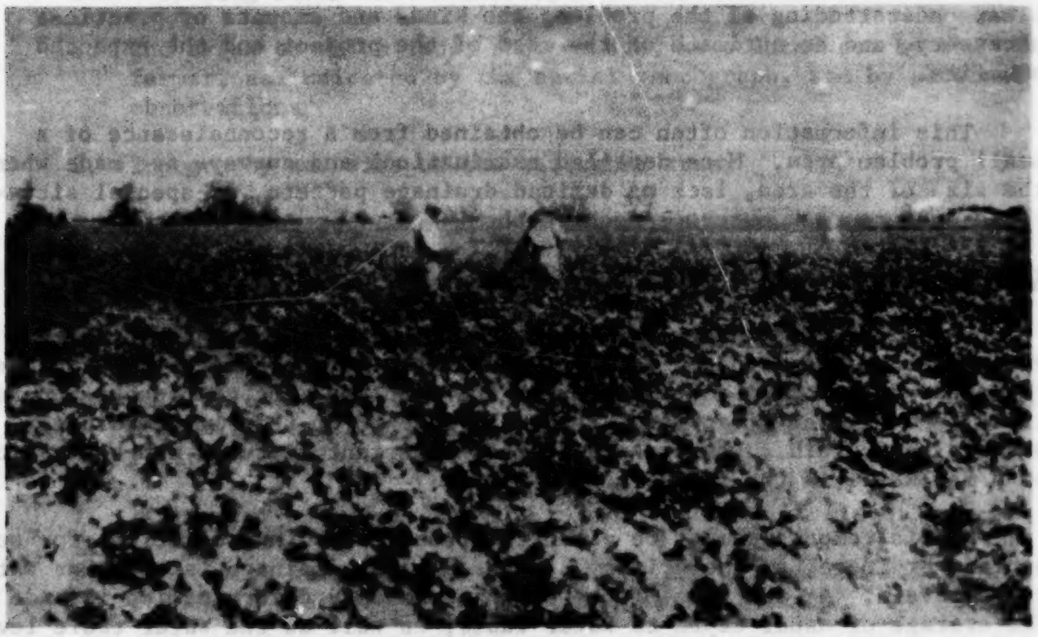


Figure 14-4 Same field as above after installation of good drainage system

2. Soils are shallow (8 to 20 inches deep) over slowly permeable subsoil or rock.

3. Soils are responsive to subsurface drainage but lack free subsurface outlet.

4. Subsurface drainage is not economically feasible.

5. Surface drainage supplements subsurface drainage.

Subsurface Drainage

Subsurface drainage involves the removal of excess ground water within the soil. Tile, pipe and mole drains are used in many cases. Open ditches constructed to adequate depths and properly located are used frequently to provide subsurface drainage. Subsurface drainage is applicable to wet sites and soils of sufficient porosity which are so located that a free outlet is available or an outlet can be obtained by pumping. It is used also to facilitate the leaching of salts from the soil and maintenance of a salt balance.

2. INVESTIGATIONS AND SURVEYS

GENERAL

When drainage of a tract of land is considered, an investigation is necessary to determine the feasibility of the project. This includes a clear understanding of the problem, the kinds and amounts of practices necessary, and an estimate of the cost of the project and the expected benefits.

This information often can be obtained from a reconnaissance of a small problem area. More detailed examinations and surveys are made when the size of the area, lack of defined drainage pattern, or special situations such as rock outcrops require them.

RECONNAISSANCE

The first step in analyzing the problem is taken during the initial visit to the area proposed for drainage. This may be done by walking over the area and becoming acquainted with the problems, the topographic conditions, and physical features. The ideal time to do this is immediately after a heavy rain. Low areas and other important features can be marked on a map while in the field.

Special emphasis must be given to ground water investigations for subsurface drainage, as the primary purpose of such drainage is to lower water table levels. At the time of the reconnaissance a determination is made of the average or usual depth to water table, as well as the water table level during the growing season. Landowners and operations may have a good estimate of water table levels based on their farming experience. In the absence of such information, local wells can be checked and, if necessary, a few borings can be made at selected locations to get some estimate of water table levels. If high water table does exist and subsurface drainage is recommended, a more detailed investigation will be required later prior to planning and designing a drainage system.

The vegetative cover should be observed and associated with certain ranges of water table level. Trees such as willow, cottonwood, and poplar often thrive in high water areas. Grasses such as the reed grasses and sedges are usually found in these areas, and there are many other wet-area plants and weeds, such as cattails and tules, too numerous to mention here. Reference is made to Section 16, National Engineering Handbook, for a detailed discussion of observation wells and piezometers.

Maps, hand level, and a soils auger should be used in the reconnaissance. Aerial photographs, conservation survey maps and county and U.S.G.S. survey maps are helpful as sources of information and as a guide in recording data, such as limits of areas to be improved, location of outlet, natural and artificial channels and improvements, probable location of proposed improvements, general land slopes, channel slopes, and watershed boundaries. Pacing or scaling from a map and hand level shots provide a means of estimating approximate channel grades, depths, and sizes. The soils auger, with extensions, provides a means of making essential subsoil examinations and determining water table levels at depths commonly needed for most sites. Orchard-type augers are the most suitable for examining soils, especially sandy, gravelly, or organic soils.

The following items should be noted:

1. The areas on which crops show damage, as pointed out by the farmer, as indicated by the aerial photograph, and by personal observations.
2. Topography and size of the watershed area.
3. Size, extent and ownership of the area needing drainage.
4. Location of the drainage outlet and its condition.
5. Location, condition, and approximate size of waterways.
6. General character of soil throughout the area needing drainage, including land capability, land use, crops and yields, and salinity or alkalinity.
7. High-water marks of damaging floods and date of flood.
8. Pipelines, roads, culverts, bridges, and irrigation facilities and their possible effect on the drainage system.
9. Problems of outside water from hill land or floods and possible disposal areas and control methods.

10. Condition of areas contributing outside water and possible treatment needed on these areas to reduce runoff or erosion debris.

11. Condition of any existing drainage system and reasons for failure or inadequacy.

12. Estimate of surveys needed.

13. Type of construction equipment available.

14. Feasibility.

This information may be obtained for small jobs by the technician when he goes over the farm with the farmer. He can then make plans for obtaining engineering and other survey data and needed information.

The intensity of this investigation and the makeup of the investigation party depend upon the size of the area and the complexity of the problem. In all cases as much information as possible should be obtained from local farmers and residents. It is important that the investigation be extensive enough to provide a clear picture of the size and extent of the drainage problem.

ENGINEERING SURVEYS

General

The size and complexity of the area to be drained determines the kinds and number of surveys needed. For the smaller, simple jobs a few lines of levels at key locations, a few soil borings to determine water table levels and the need for subsurface drainage, determination of the approximate drainage area, and a rough cost estimate, frequently are all that the technician needs to obtain.

The objective of a survey for design purpose is to obtain elevations, topography, and other field information necessary to design the system and prepare plans, specifications and estimates of quantities of work to be performed. Only that field information should be gathered which is needed for these purposes.

Drainage Outlet

The first major engineering survey job is to determine the location and adequacy of the drainage outlet. Enough level readings and measurements should be made to enable the technician to reach a sound decision. The proper functioning of the entire drainage system hinges upon this point. An engineer should be consulted if there is any doubt regarding the adequacy of the outlet.

In determining adequacy of outlets the following basic requirements should be met:

1. The capacity of the outlet should be such that the design flow can be discharged at an elevation equal to or less than that of the hydraulic gradeline used for design of the project. Where the outlet is a channel, the stage-discharge relationship should be determined. This should take into consideration the runoff from the entire watershed, computed in the same manner as for the project design.

2. The capacity of the outlet also must be such that the discharge from the project area after making the drainage improvements will not result in damaging stage increases below the end of the project channel.

3. The depth of the outlet should be such that any needed subsurface drains may be discharged into it above normal low waterflow.

4. Flow conditions in the outlet should be capable of maintaining equilibrium with the sediment transport for the project channel. There should not be excessive scour or deposition of sediment in the outlet.

If the outlet is found to be inadequate, and it is not feasible under present conditions to make it so, or to pump, then it is useless to make further surveys

Establishing Bench Marks

Begin the level work by tying into an established bench mark or establishing a convenient temporary bench mark (TBM) based on survey needs. As the survey progresses, establish other bench marks as needed. Properly located bench marks will be helpful and timesaving during the layout and construction of the job. Temporary bench marks such as spikes or large nails in notches of large tree roots should be used. Use of wood stakes or nails in small fenceposts for the more important bench marks is poor practice.

Topographic Survey

Topographic information of the area to be drained is necessary except on fields with sufficient slope so that the general lay of the land is obvious. This information is used on the flatter areas for planning land grading or locating field ditches, drains or other facilities. The amount and kind of topographical survey depends upon the drainage problem and the topography of the land, varying from a detailed grid or contour map to random elevations, valley cross sections, and locating important features. Refer to Chapter 1 of this manual for survey procedures. Some of the details to observe in obtaining topographic information for drainage are:

1. Obtain elevations at 100- to 300-foot horizontal intervals on flatland depending on how nearly level the land is and whether the drainage pattern is apparent from inspection. Take additional elevations in all low or depressed areas. The flatter the land the more important it is to take elevations at relatively close intervals.

2. Where random ditches are to be used to drain depressions or pockets, vary the amount of survey data according to ground conditions. Elevations at close intervals will be necessary if depressed areas are numerous, whereas, in areas with few depressions, a skelton topographic map may suffice. In either case, the survey should be in sufficient detail to locate and determine elevations of depressed areas and the best outlets.

3. Physical features should be obtained of adjacent land affecting the drainage of the proposed area. Especially, obtain the location and elevations of all ditch bottoms or drainageways, size of opening and flow line elevations of culverts and bridges, and any other similar information needed to plan the drainage system.

Profile Survey

The procedure for running profiles is described in Chapter 1 of this manual. Slightly different procedures for profiles are required if there is an existing ditch or if a new ditch is to be constructed.

Profiles Where There is an Existing Ditch

This condition requires the following steps:

1. Obtain elevations of the natural ground alongside the ditch and of the old ditch bottom at 100- to 500-foot intervals. Elevations of all critical points between stations should also be taken.

2. Obtain the following on existing culverts and bridges along the ditch line: station, inlet and outlet invert elevations, size of opening, length, and kind of material (concrete, C.M.P., etc.). Also obtain elevations of top of road crossing and structure and, in case of bridges, the elevation of the bottom of the stringers. Where bridges will be affected, the elevation of the bottom of the footings and of the bridge piers and abutments and their condition should be noted.

3. Where laterals or tributaries discharge into the ditch, note the station and the bottom elevation of the ditch at the point of entrance and any other pertinent data that would be useful in design.

4. Locate, describe, and obtain elevations as required or any other physical features along the ditch that will affect the design, such as cattle ramps, fences, surface flow entering ditch, rock outcrops, etc.

Profiles on New Ditch Lines

These differ from profiles of existing ditches in that the centerline of the proposed ditch must be located first. Information and elevations along the proposed ditch line should be obtained as specified for existing ditches.

Cross Sections

The procedure for surveying cross sections is described in Chapter 1 of this manual.

1. Individual shots should be taken at all prominent breaks to accurately reflect the cross section of the ditch.
2. Take cross sections at intervals of 100 to 500 feet on existing ditches depending on the irregularity of topography and the variation in ditch size. Cross sections may show elevation and extent of low areas needing drainage if this information was not obtained by the preliminary profiles.
3. When no ditch exists, cross sections are not always necessary unless the ground level on either side of the proposed ditch centerline has obvious differences in elevation.

Other Field Information

Other field data should be gathered at the time of the design survey. Some of them are as follows:

1. The area to be drained should be delineated on an aerial photograph or other suitable map.
2. The drainage area should also be outlined if it is a factor that will affect design of the system.
3. Information regarding crops to be grown and farm machinery likely to be used after drainage since they may affect the proposed design.
4. Soil borings are necessary unless the characteristics of the soil materials to a depth of at least one foot below the proposed depth of ditch are known for areas in need of surface drainage and to twice the depth of drain where subsurface drainage is needed.
5. Information on frequency and depth of flooding on the area to be drained is necessary. Drift marks of previous flooding often may be seen on trees, culverts or fenceposts. Elevation and frequency of high water should be obtained if it will have a bearing on the ditch design.

Plotting Survey Data

Chapter 5 of this manual gives information on the preparation of engineering plans. Some personal preference in the preparation is allowed.

3. SURFACE DRAINAGE PRACTICE

GENERAL

In flatland areas, where drainage is needed, water floods over the land. Slopes usually are not great enough to cause erosion from the flowing water, and the object of drainage systems is to remove the excess water before it damages the crops. This differs from erosion control work, in which the object is to provide for and control the erosive velocities of peak floodflows.

DRAINAGE RUNOFF

Ditches for drainage of common field crops usually are designed to remove runoff water from the drainage area within a 24-hour period following an ordinary rain. Some surface flooding of the land during this period is permissible.

Some high-value and specialty crops require a more rapid rate of removal of runoff water to prevent crop damage. For these crops, a 6- to 12-hour removal interval may be necessary during the growing season.

The basis of removal is called the drainage coefficient which is the rate of water removal per unit of area used in drainage design. For subsurface drainage systems, the drainage coefficient usually is expressed in inches in 24 hours or cubic feet per second per unit of area. For surface drainage the coefficient is usually expressed in terms of flow rate per unit of area, which varies with the size of the area.

DETERMINING DRAINAGE RUNOFF

Curves for determining runoff for drainage design have been prepared in most of the humid areas of the United States. They are based on the climate, soils, topography and agriculture of the particular area. Curves proposed by John G. Sutton, known as the SCS drainage runoff curves (A, B, C, D curves), have been used in the northern portion of the country for about 30 years. (See Exhibits 14-1 and 14-2.) The Red River Valley runoff curves (M and S) based on the SCS drainage curves, and adjusted to the Red River Valley of the North, have been in use for about 25 years. See State Standards and Specifications for applicable SCS drainage runoff curves.

Other drainage curves which have been developed over a long period of time have been used in the Southeastern, Southwestern and Western areas. Due to the wide variations in rainfall, soils, crops, and topography, drainage design should be based on drainage coefficients applicable to local conditions. The capacity for design given by most of the curves varies in accordance with the general formula:

$$Q = CM^{5/6}$$

Where Q = flow in c.f.s. for which the ditch is to be designed.
C = the appropriate drainage coefficient for 1 square mile of watershed.
M = square miles of watershed.

This formula provides an economical and effective design for open ditches if C is selected properly. See Section 16, SCS National Engineering Handbook, and State Standards and Specifications for C values to be used.

Capacities for drainage ditches in arid irrigated areas usually are determined by the leaching requirement and amount of return flow from irrigation water. If surface runoff from precipitation is involved, the above formula with appropriate value of C may be used. For many ditches, in the arid irrigated areas, the depth required, rather than required capacity, will govern the size of the ditch.

Typical drainage curves, Exhibit 14-3, are included to provide information for following the example below. The procedures used in the example may be applied to other curves or runoff discharges.

Composite Curves

Composite curves are used where the runoff from the lands draining into a ditch must be based on different drainage curves. The computing of equivalent drainage areas for areas requiring different drainage curves provides a method of determining the design capacity of ditches.

This method consists of determining the runoff from the acreage of one type of land and converting it to the equivalent acreage of another type of land so that the acreage may be added together and used to find the discharge from the area.

Example:

A watershed contains 500 acres of land requiring the runoff curve $Q = 45M^{5/6}$ and 200 acres of land requiring the runoff curve $Q = 22\tfrac{1}{2}M^{5/6}$. It will be necessary to convert to either $Q = 45M^{5/6}$ or $Q = 22\tfrac{1}{2}M^{5/6}$ curve depending on the curve to be used on land below this watershed. Assume the removal rate of this land to be $Q = 45M^{5/6}$. The discharge from 200 acres on the $Q = 22\tfrac{1}{2}M^{5/6}$ curve is 8.4 c.f.s. This is equivalent to 86 acres on the $Q = 45M^{5/6}$ curve. The total equivalent watershed would be 500 acres plus 86 acres or 586 acres. The total discharge from 586 acres on the $Q = 45M^{5/6}$ curve is found to be 42 c.f.s. Therefore, the 586 acres and the 42 c.f.s. are used in computations below this watershed.

SURFACE DRAINAGE SYSTEMS

Surface drainage systems may consist of field ditches, land forming or a combination of the two, and a system of ditches to carry the drainage water to the outlet. The drainage system should provide for an orderly removal of excess water from the surface of the land.

Field Ditches

Field ditches are shallow graded ditches for collecting water within a field, usually constructed with flat side slopes for ease in crossing. They may drain basins or depressional areas, collect or intercept flow from land surfaces or channeled flow from natural depressions, plow furrows, crop row furrows, and bedding systems. State Drainage Guides and Standards and Specifications contain criteria regarding side slopes, grades, spacing, and depth of drainage field ditches. Tables are usually used to determine the ditch section.

Type of Ditch Systems

Ditches should be located to fit the farm operations. They should have capacity to handle the runoff and not cause harmful erosion. The system should cause excess water to flow readily from the land to the disposal ditch. The types of ditch systems are described as follows:

Random Ditch System

This system is adapted to undulating land where only scattered wet areas require drainage. The ditches should be located so they intercept depressions and provide the least interference with farming operations (Figure 14-5). The ditches should be shallow and have side slopes flat enough for farm equipment to cross. Land grading and smoothing will help on less permeable soil to assure surface water removal.

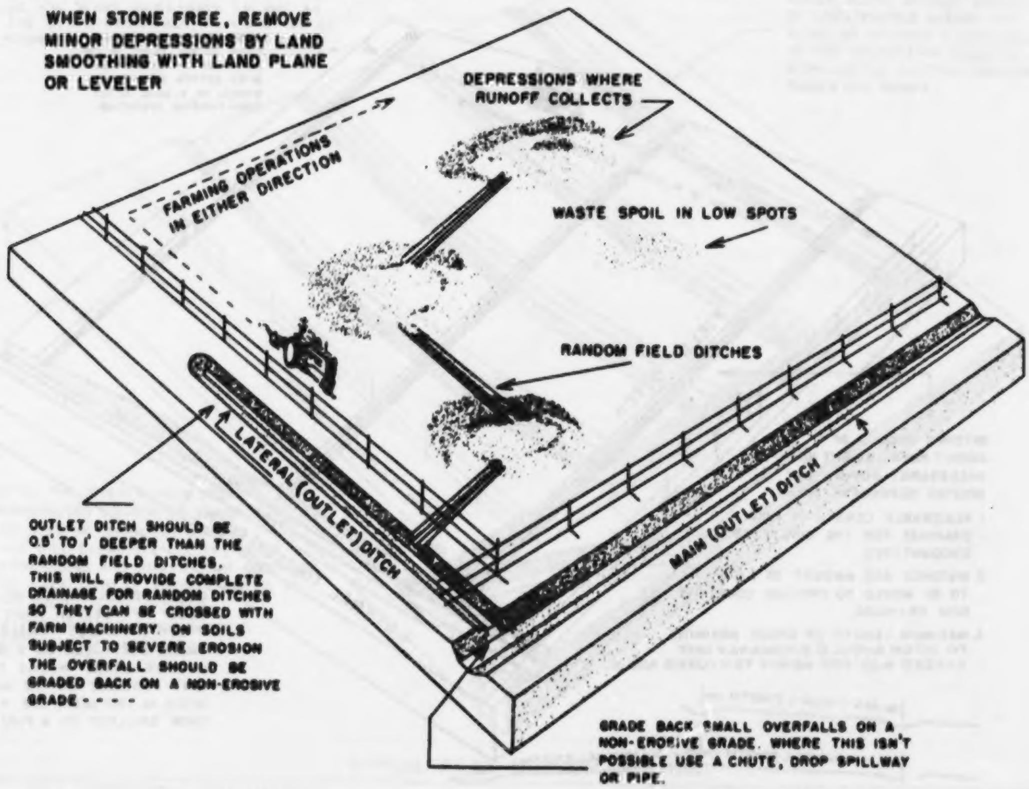
Parallel Ditch Systems

This system is applicable to land where the topography is flat and regular and where uniform drainage is needed. The ditches are established parallel but not necessarily equidistant, as shown in Figure 14-6. The direction of the land slope usually will determine the direction of the ditches as follows: field ditches will be generally perpendicular to the slope and laterals will run in the direction of the slope. The location of diversions, cross slope ditches, and access roads for farming equipment may also influence the ditch location. Spacing of the field ditches depends upon the water tolerance of crops, soils, and the uniformity of the topography. Land forming practices may be used to improve the topography and reduce the number of ditches required. Where possible, spacings should be adjusted to fit a number of "throughs" with tillage and harvesting equipment.

Cross Slope Ditch System

This system is used to drain wet sloping land, to prevent the accumulation of water from higher land, and to prevent the concentration of water in shallow pockets within a field. The field ditches work best on slopes under 2 percent. The ditch is located across the slope as straight as topography will permit (Figure 14-7). The spacing of these ditches will vary with the land slope and should be based on State Drainage Guides. The excavated material should be placed in low areas or on the downhill side of the ditch. Land grading or smoothing between the ditches will improve operation of the system.

SMOOTH AREA SO LAND WILL DRAIN TO THE LARGE DEPRESSIONS OR RANDOM DITCHES


WHEN STONE FREE, REMOVE MINOR DEPRESSIONS BY LAND SMOOTHING WITH LAND PLANE OR LEVELER
DEPRESSIONS WHERE RUNOFF COLLECTS
FARMING OPERATIONS IN EITHER DIRECTION
WASTE SPOIL IN LOW SPOTS
RANDOM FIELD DITCHES
LATERAL (OUTLET) DITCH
MAIN (OUTLET) DITCH
OUTLET DITCH SHOULD BE 0.5' TO 1' DEEPER THAN THE RANDOM FIELD DITCHES. THIS WILL PROVIDE COMPLETE DRAINAGE FOR RANDOM DITCHES SO THEY CAN BE CROSSED WITH FARM MACHINERY. ON SOILS SUBJECT TO SEVERE EROSION THE OVERFALL SHOULD BE GRADED BACK ON A NON-EROSIVE GRADE - - - -
GRADE BACK SMALL OVERFALLS ON A NON-EROSIVE GRADE. WHERE THIS ISN'T POSSIBLE USE A CHUTE, DROP SPILLWAY OR PIPE.

CROSS SECTION OF RANDOM DITCH

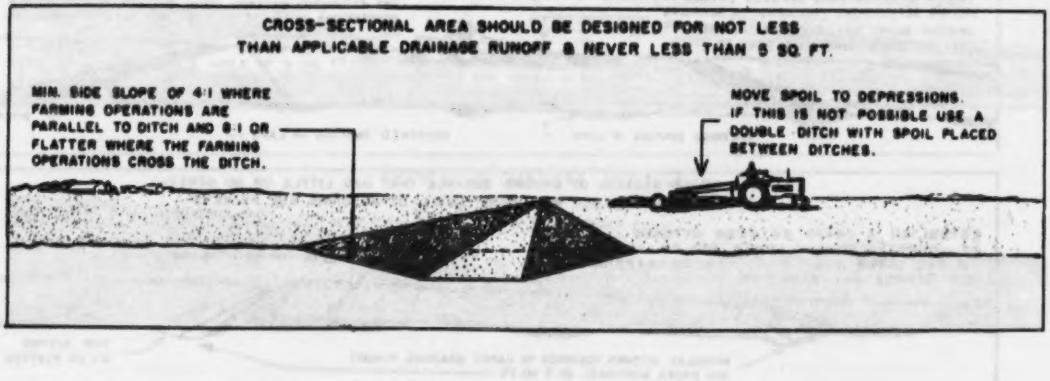

CROSS-SECTIONAL AREA SHOULD BE DESIGNED FOR NOT LESS THAN APPLICABLE DRAINAGE RUNOFF & NEVER LESS THAN 5 SQ. FT.
MIN. SIDE SLOPE OF 4:1 WHERE FARMING OPERATIONS ARE PARALLEL TO DITCH AND 8:1 OR FLATTER WHERE THE FARMING OPERATIONS CROSS THE DITCH.
MOVE SPOIL TO DEPRESSIONS. IF THIS IS NOT POSSIBLE USE A DOUBLE DITCH WITH SPOIL PLACED BETWEEN DITCHES.

Figure 14-5 Random ditch system of surface drainage

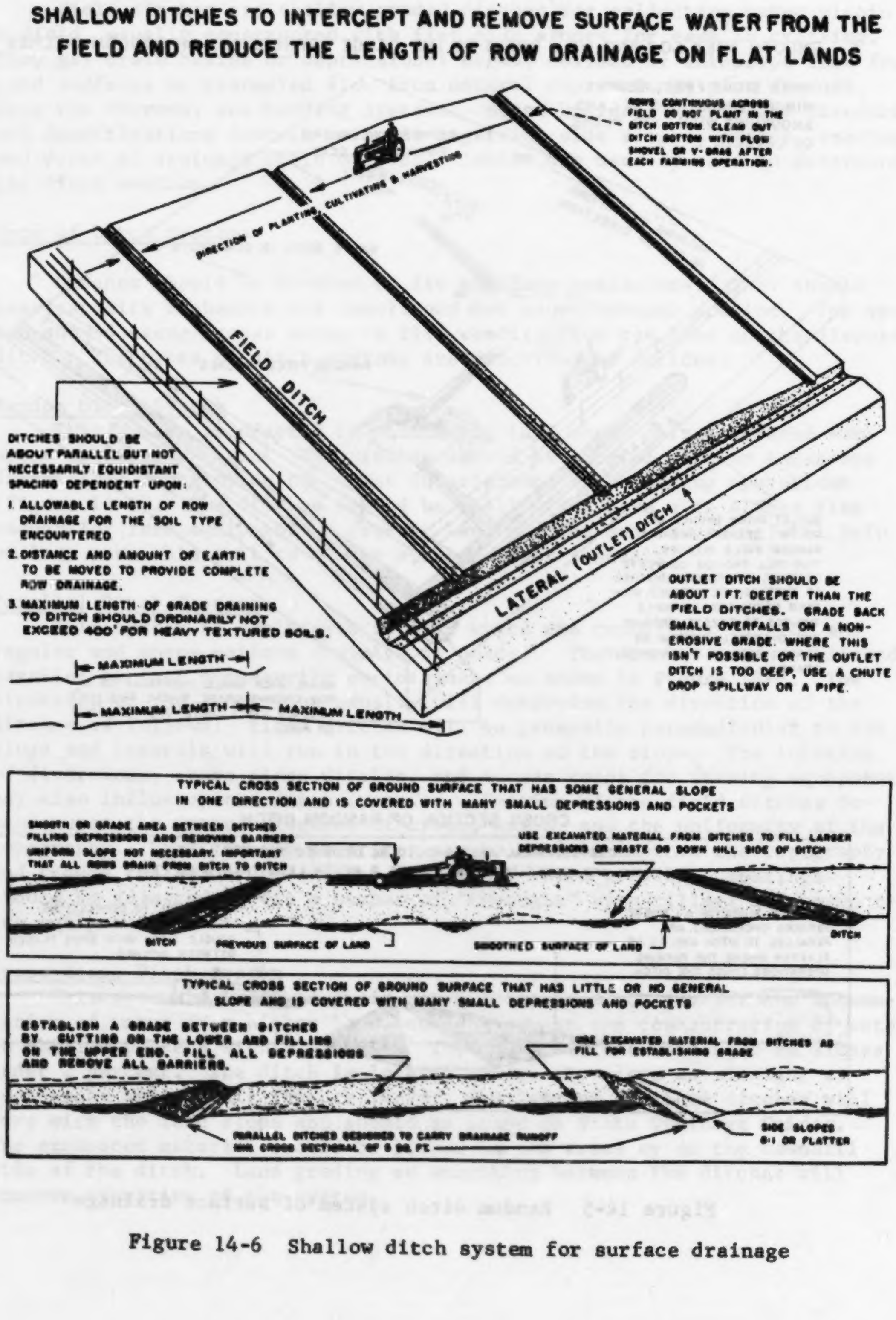

SHALLOW DITCHES TO INTERCEPT AND REMOVE SURFACE WATER FROM THE FIELD AND REDUCE THE LENGTH OF ROW DRAINAGE ON FLAT LANDS
ROWS CONTINUOUS ACROSS FIELD DO NOT PLANT IN THE DITCH BOTTOM. CLEAN OUT DITCH BOTTOM WITH PLOW SHOVEL OR V-DRAG AFTER EACH FARMING OPERATION.
DIRECTION OF PLANTING, CULTIVATING & HARVESTING
FIELD DITCH
DITCHES SHOULD BE ABOUT PARALLEL BUT NOT NECESSARILY EQUIDISTANT SPACING DEPENDENT UPON:
1. ALLOWABLE LENGTH OF ROW DRAINAGE FOR THE SOIL TYPE ENCOUNTERED
2. DISTANCE AND AMOUNT OF EARTH TO BE MOVED TO PROVIDE COMPLETE ROW DRAINAGE.
3. MAXIMUM LENGTH OF GRADE DRAINING TO DITCH SHOULD ORDINARILY NOT EXCEED 400' FOR HEAVY TEXTURED SOILS.
MAXIMUM LENGTH
MAXIMUM LENGTH
MAXIMUM LENGTH
LATERAL (OUTLET) DITCH
OUTLET DITCH SHOULD BE ABOUT 1 FT. DEEPER THAN THE FIELD DITCHES. GRADE BACK SMALL OVERFALLS ON A NON-EROSIVE GRADE. WHERE THIS ISN'T POSSIBLE OR THE OUTLET DITCH IS TOO DEEP, USE A CHUTE DROP SPILLWAY OR A PIPE.
TYPICAL CROSS SECTION OF GROUND SURFACE THAT HAS SOME GENERAL SLOPE IN ONE DIRECTION AND IS COVERED WITH MANY SMALL DEPRESSIONS AND POCKETS
SMOOTH OR GRADE AREA BETWEEN DITCHES FILLING DEPRESSIONS AND REMOVING BARRIERS
UNIFORM SLOPE NOT NECESSARY. IMPORTANT THAT ALL ROWS DRAIN FROM DITCH TO DITCH
USE EXCAVATED MATERIAL FROM DITCHES TO FILL LARGER DEPRESSIONS OR WASTE ON DOWN HILL SIDE OF DITCH
DITCH
PREVIOUS SURFACE OF LAND
SMOOTHED SURFACE OF LAND
DITCH
TYPICAL CROSS SECTION OF GROUND SURFACE THAT HAS LITTLE OR NO GENERAL SLOPE AND IS COVERED WITH MANY SMALL DEPRESSIONS AND POCKETS
ESTABLISH A GRADE BETWEEN DITCHES BY CUTTING ON THE LOWER AND FILLING ON THE UPPER END. FILL ALL DEPRESSIONS AND REMOVE ALL BARRIERS.
USE EXCAVATED MATERIAL FROM DITCHES AS FILL FOR ESTABLISHING GRADE
PARALLEL DITCHES DESIGNED TO CARRY DRAINAGE RUNOFF MIN. CROSS SECTIONAL OF 5 SQ. FT.
SIDE SLOPES 8:1 OR FLATTER

Figure 14-6 Shallow ditch system for surface drainage

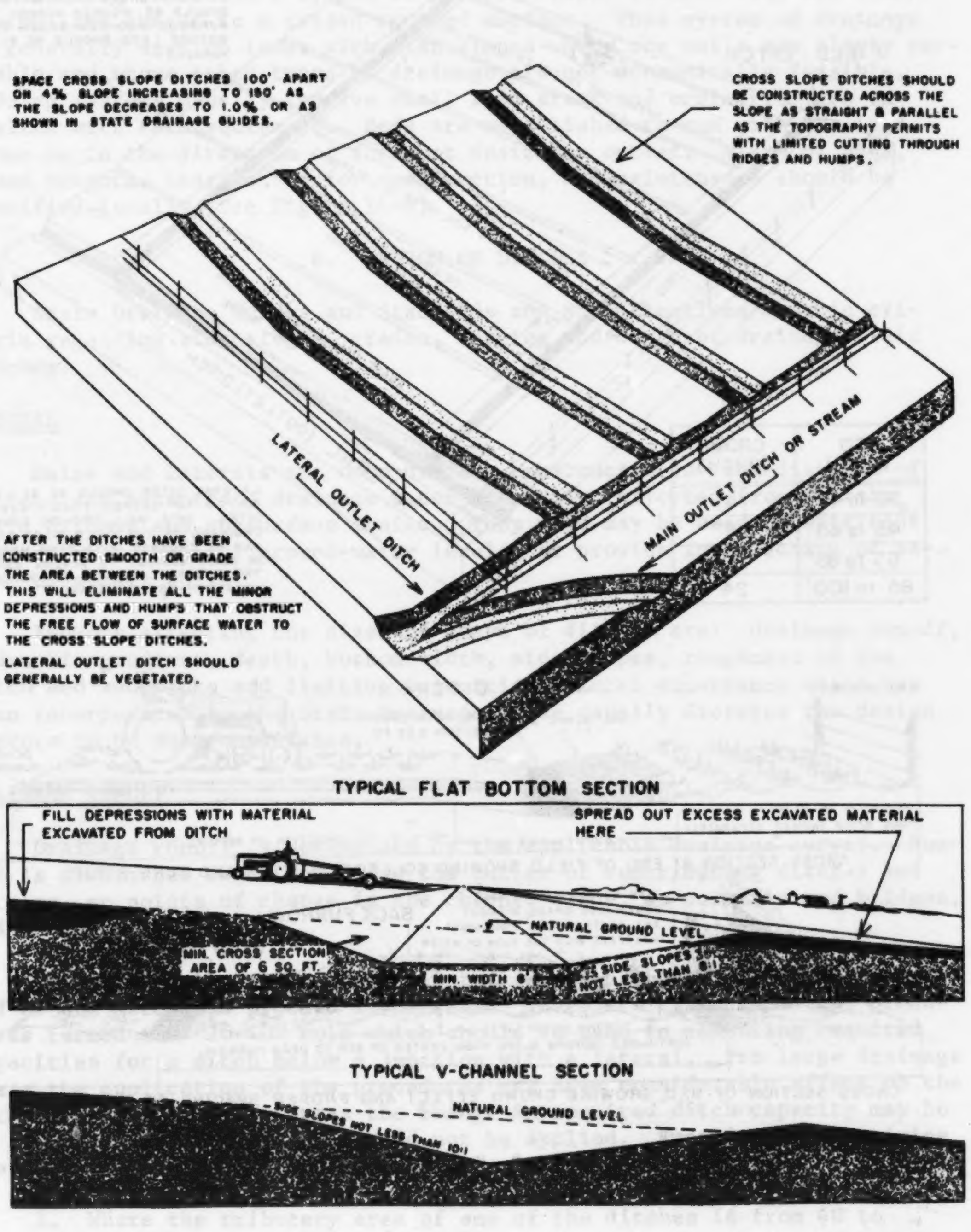
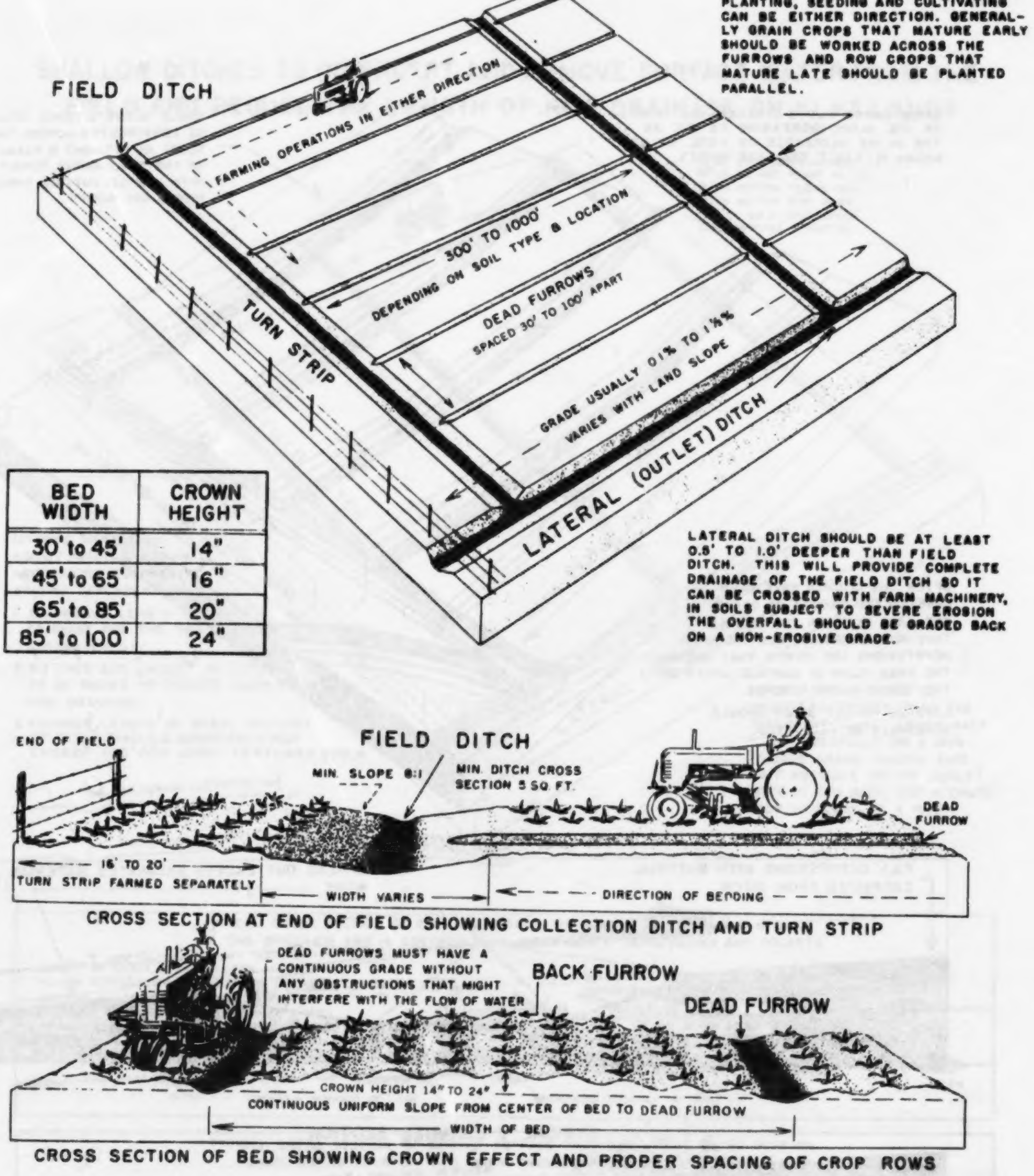

SPACE CROSS SLOPE DITCHES 100' APART ON 4% SLOPE INCREASING TO 150' AS THE SLOPE DECREASES TO 1.0% OR AS SHOWN IN STATE DRAINAGE GUIDES.
CROSS SLOPE DITCHES SHOULD BE CONSTRUCTED ACROSS THE SLOPE AS STRAIGHT & PARALLEL AS THE TOPOGRAPHY PERMITS WITH LIMITED CUTTING THROUGH RIDGES AND HUMPS.
LATERAL OUTLET DITCH
MAIN OUTLET DITCH OR STREAM
AFTER THE DITCHES HAVE BEEN CONSTRUCTED SMOOTH OR GRADE THE AREA BETWEEN THE DITCHES. THIS WILL ELIMINATE ALL THE MINOR DEPRESSIONS AND HUMPS THAT OBSTRUCT THE FREE FLOW OF SURFACE WATER TO THE CROSS SLOPE DITCHES.
LATERAL OUTLET DITCH SHOULD GENERALLY BE VEGETATED.
TYPICAL FLAT BOTTOM SECTION
FILL DEPRESSIONS WITH MATERIAL EXCAVATED FROM DITCH
SPREAD OUT EXCESS EXCAVATED MATERIAL HERE
NATURAL GROUND LEVEL
MIN. CROSS SECTION AREA OF 6 SQ. FT.
MIN. WIDTH 6'
SIDE SLOPES NOT LESS THAN 8:1
TYPICAL V-CHANNEL SECTION
NATURAL GROUND LEVEL
SIDE SLOPES NOT LESS THAN 10:1

Figure 14-7 Cross slope ditch system of surface drainage-terrace type drain



THE FURROWS DRAIN TO FIELD DITCHES PLANTING, SEEDING AND CULTIVATING CAN BE EITHER DIRECTION. GENERALLY GRAIN CROPS THAT MATURE EARLY SHOULD BE WORKED ACROSS THE FURROWS AND ROW CROPS THAT MATURE LATE SHOULD BE PLANTED PARALLEL.

LATERAL DITCH SHOULD BE AT LEAST 0.5' TO 1.0' DEEPER THAN FIELD DITCH. THIS WILL PROVIDE COMPLETE DRAINAGE OF THE FIELD DITCH SO IT CAN BE CROSSED WITH FARM MACHINERY. IN SOILS SUBJECT TO SEVERE EROSION THE OVERFALL SHOULD BE GRADED BACK ON A NON-EROSIVE GRADE.

BED WIDTH	CROWN HEIGHT
30' to 45'	14"
45' to 65'	16"
65' to 85'	20"
85' to 100'	24"

FIELD DITCH
FARMING OPERATIONS IN EITHER DIRECTION
300' TO 1000' DEPENDING ON SOIL TYPE & LOCATION
DEAD FURROWS SPACED 30' TO 100' APART
TURN STRIP
GRADE USUALLY 0.1% TO 1½% VARIES WITH LAND SLOPE
LATERAL (OUTLET) DITCH
END OF FIELD
FIELD DITCH
MIN. SLOPE 8:1
MIN. DITCH CROSS SECTION 5 SQ. FT.
DEAD FURROW
16' TO 20'
TURN STRIP FARMED SEPARATELY
WIDTH VARIES
DIRECTION OF BEDDING
DEAD FURROWS MUST HAVE A CONTINUOUS GRADE WITHOUT ANY OBSTRUCTIONS THAT MIGHT INTERFERE WITH THE FLOW OF WATER
BACK FURROW
DEAD FURROW
CROWN HEIGHT 14" TO 24"
CONTINUOUS UNIFORM SLOPE FROM CENTER OF BED TO DEAD FURROW
WIDTH OF BED

CROSS SECTION AT END OF FIELD SHOWING COLLECTION DITCH AND TURN STRIP

CROSS SECTION OF BED SHOWING CROWN EFFECT AND PROPER SPACING OF CROP ROWS

Figure 14-8 Surface drainage bedding

Bedding

Bedding resembles a system of parallel field ditches with the intervening land shaped to a raised rounded surface. This system of drainage is generally used on lands with flat slopes where the soils are slowly permeable and where other types of drainage are not economically feasible. Bedding systems usually involve small land areas and ordinarily are installed with farm equipment. Beds are established to run with the land slope or in the direction of the most desirable outlet. Width of beds, crown heights, instruction for construction, and maintenance should be specified locally (See Figure 14-8).

4. DESIGN OF DITCHES

State Drainage Guides and Standards and Specifications contain criteria regarding side slopes, grades, spacing and depth of drainage field ditches.

GENERAL

Mains and laterals are open ditches constructed for the disposal of surface and subsurface drainage water primarily collected from surface field ditches and subsurface drains. They also may be used to intercept ground water, control ground-water levels, or provide for leaching of saline or alkali soils.

Factors affecting the size and shape of ditches are: drainage runoff, hydraulic gradient, depth, bottom width, side slopes, roughness of the ditch bed and banks and limiting velocities. Local experience which has been incorporated in the State Drainage Guide usually dictates the design factors to be used on ditches.

DRAINAGE RUNOFF

Drainage runoff is determined by the applicable drainage curves. Runoff is determined above and below the outlet of contributing ditches and streams, at points of change in the channel slope, at culverts and bridges, and at the outlet.

It is general practice to begin the runoff calculations at the upper end of the ditch and proceed downstream. There are three empirical procedures termed the "20-40" rule which should be used in computing required capacities for a ditch below a junction with a lateral. For large drainage areas the application of the procedures may have considerable effect on the ditch design. On small areas the change in required ditch capacity may be so slight that the procedures need not be applied. Experience in applying the "20-40" rule will guide the designer in its use.

1. Where the tributary area of one of the ditches is from 40 to 50 percent of the total tributary area, the required capacity of the channel below the junction shall be determined by adding the required design capacities of the ditches above the junction.

This is based upon the assumption that the flows from two watersheds of about the same size may reach the junction about the same time and therefore the ditch capacity below the junction should be the sum of the two flows. This rule should be used in all cases for areas less than 300 acres.

2. Where the watershed area of a lateral is less than 20 percent of the total watershed area immediately below the junction, the design capacity of the ditch below the junction shall be determined from the drainage curve for the total watershed area below the junction.

   This is used where a ditch draining a small area joins a ditch draining a much larger area.

3. Where the watershed area of a lateral is in the range of from 20 to 40 percent of the total watershed area, the discharge shall be proportioned from the smaller discharge at 20 percent to the larger discharge at 40 percent. In this range the discharges should be computed by both methods and the difference in c.f.s. obtained. Then, the design discharge for the channel below the junction should be obtained by interpolation.

   This is a combination of rules 1 and 2 and is illustrated by the following:

   Assume a lateral ditch draining 350 acres joins a ditch draining 650 acres making a total drainage area below the junction of 1,000 acres. One of the watersheds is 35 percent of the total watershed and rule 3 will apply. Assume that the curve developed from $Q = 45M^{5/6}$ applies. Find the discharges with Exhibit 14-3.

	Watershed Area Acres		Runoff $Q = 45M^{5/6}$ cfs
Rule 1	350		27
	650		45
		Total	72
Rule 2	1,000		65
		Difference	7

   The difference between 20 and 40 percent is 20 percent. Thirty-five percent is 15/20 of the difference between 20 and 40 percent. 15/20 of 7 c.f.s. is 5.2 c.f.s. (Use 5.) Add 5 c.f.s. to 65 c.f.s. to arrive at 70 c.f.s. for the capacity of the ditch below the junction.

In addition to design flows for ditches below junctions, design flows are required at other points along the ditch and these points will be discussed later.

DITCH ALIGNMENT

The ditch should be as straight as practical. Where it is necessary to change direction of the ditch a simple curve should be used. (See Chapter 1.) Curves with a radius of not less than 600 feet are desirable; but due to the need to follow old ditches or swales, decrease the waste area caused by the use of long radii curves, or to conform to ownership boundaries, sharper curves may be used. When the ditch flows are small and the velocities low, gentle curvature is not so important.

HYDRAULIC GRADIENT

The hydraulic gradient is the slope of the hydraulic gradeline (water surface) and is important in determining flow velocity. The importance of proper location of the gradeline increases as ditch flows become greater. The profile of the channel should be plotted and the location and elevation of control points shown. Control points are used to help select the maximum elevation of the hydraulic gradeline desired for the ditch. The control points may include but are not limited to the following:

1. Natural ground elevations along the route of the proposed ditch.
2. Location, size, and elevation of critical low areas to be drained. These are obtained from the surveys or from maps.
3. Establish hydraulic gradeline for ditches from the critical areas to the design ditch. Plot the elevation where the side ditch hydraulic gradeline meets the design ditch as a control point.
4. When laterals or natural streams enter the design ditch, the same procedure outlined in item 3 should be used.
5. Bridges across drainage ditches should not reduce the design cross-section area. Where feasible to do so the hydraulic gradeline should be placed one foot below the stringers of the bridge. The allowable head loss on culverts should be kept low. On agricultural drainage the allowable head loss generally should not exceed 0.5 foot.
6. Elevations of buildings or other property within the area to be protected from overflow.
7. If the ditch being designed is to outlet into an existing ditch or natural stream, the elevation of the water in the outlet ditch or stream against which the designed ditch must discharge should be used as a control point. The water surface elevation in the outlet ditch may be determined from recorded data, from local people, or from high-water marks. Another method of obtaining this elevation is to determine the depth of flow in the outlet ditch by applying the same flow design basis as used for the proposed ditch. For small outlet ditches in rather flat topograpy, the water elevation may be estimated at the bank-full stage.

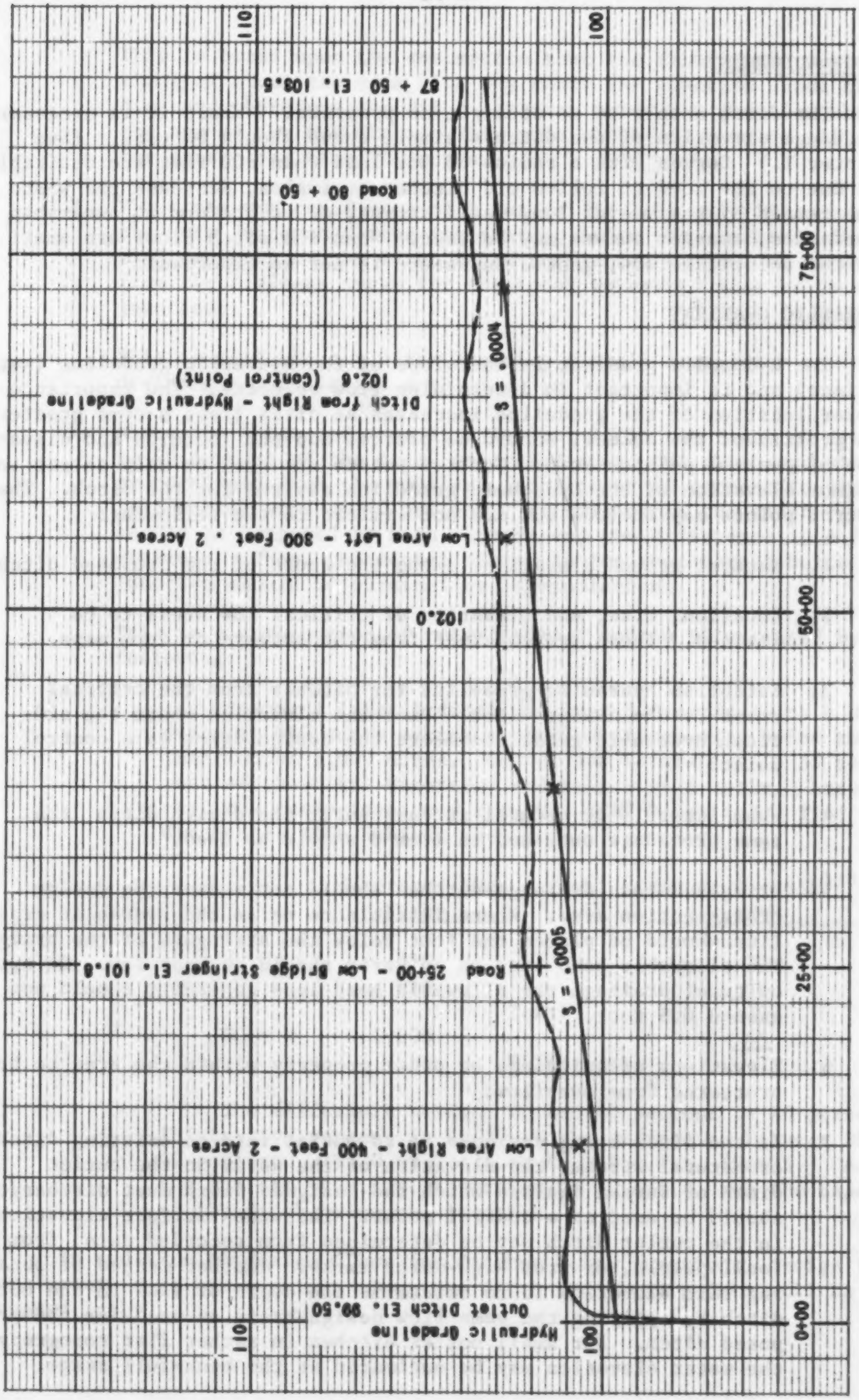


Figure 14-9 Establishing hydraulic gradeline

The control points should be connected with a line on the profile. The hydraulic gradeline is drawn through or below the control points. The grades should be as long as possible, breaking the grades only where necessary to stay close to the control points. Figure 14-9 illustrates this.

If the hydraulic gradeline has been well established, it will not be altered except at structures with head losses. At these points the head loss will be shown upstream from the structure as a backwater curve which will change the hydraulic gradient, but usually for only a short distance.

DESIGN METHODS

Ditch design may be done by reaches (specific length of ditch). One method is to design the ditch for the required capacity of the lower end of the reach and use that section throughout the reach. Using this method, the upper end of the reach will be overdesigned. Reaches should be selected so that overdesigning will be held to practical limits. In order to reflect as nearly as possible the flow conditions, the selection of the length of reach is important. The beginning and the end of reaches usually are determined by the following:

1. Tributary junctions where the required ditch capacity changes.

2. A break in grade of the water surface profile.

3. Increasing drainage area may require that an otherwise long reach be divided into shorter reaches. A knowledge of where water enters the ditch, as well as the amount, will determine how the reach should be divided so that overdesigning of the ditch will be minimized.

4. Bridges or culverts may be used to begin or end a reach although it is not necessary.

After the hydraulic gradeline has been established, the drainage area and the required ditch capacity at the upper and lower end of each reach is determined. At this time the drainage area and the required capacity for any structure should be obtained for use in design of the structure.

Ditch design by the point method is sometimes preferred. In this method the required depth of the ditch is determined at the control points for the discharges at those points. This assumes that the runoff throughout the reach enters uniformly along the reach. The depth at the beginning and end of a reach will differ. The depths are established below the hydraulic gradeline and the bottom of the ditch drawn between the points. The slope of the ditch bottom normally will not be parallel to the hydraulic gradeline. At points where concentrated flows enter, a change in either depth, width or both may be required. At these points a transition may be required.

Ditch Depth

Factors that must be considered in establishing the depth of a ditch for drainage are: Depth to provide the capacity for removing the surface runoff plus freeboard; depth to provide outlet for subsurface drainage; and depth to clear bridges.

1. Surface discharge. Sufficient depth must be provided so that surface runoff can flow freely into the ditch under design conditions. Where the hydraulic gradeline has been established as shown in Figure 14-9, the depth of the ditch is measured down from the gradeline. Where the ditch grade is established first, the depth is measured upward to locate the water surface. Using this last method, the water surface elevation obtained must be checked in relation to control points. The depth of each reach should be determined to meet the needs of the specific area involved.

2. Subsurface discharge. Ditches used to serve as outlets for subsurface drains should be deep enough to provide free outfall from the underdrain with about one foot of clearance between the invert of the drain and the normal low water flow in the ditch. Ditches designed to intercept subsurface flows or to serve as an outlet for ditches installed for subsurface drainage should be deep enough to serve these conditions. The required depth sometimes results in the ditch capacity being in excess of the design flow requirements for surface runoff and the actual hydraulic gradeline may be substantially lower. This often occurs at the upper ends of small drainage systems.

Grade of Ditch Bottom

If uniform flow in the ditch is assumed, the ditch grade will have the same slope as the hydraulic gradeline. The required depth of the ditch is determined and measured down from the hydraulic gradeline. These points connected are the bottom grade of the ditch.

A designer may follow the method above in locating the grade but may prefer to adjust the bottom grade to eliminate the need for transitions. The method of locating the ditch bottom given above is generally satisfactory in designing a new ditch. The example illustrates the use of surface control points to establish the hydraulic gradelines. Especially in the reconstruction of existing ditches, the elevations of the existing ditch bottom, bridge footings and soil strata must be considered as control points in establishing the bottom of the designed ditch. At times, it may be more convenient to locate the bottom of the ditch from these control points and measure the design depth up from the bottom to locate the hydraulic grade (water surface). Cross sections must be used in deciding upon the hydraulic grade or the ditch bottom.

Ditch Side Slopes

These are determined primarily by the stability of the materials through which the ditch is dug and the methods of maintenance to be practiced. Maintenance requirements may necessitate modification. The steepest side slopes recommended for ordinary conditions for mains or laterals are as follows:

Soil	Side Slopes
Loam	2:1
Clay	1½:1
Peat, muck and sand	1:1

Experience in certain types of soil may indicate that steeper side slopes may be used. Maintenance requirements may justify flattening side slopes. Ditch side slopes which may be used with various maintenance methods are given in Table 14-1.

Table 14-1 Ditch side slopes recommended for maintenance

Type of Maintenance	Recommended Steepest Side Slopes	Remarks
Mowing	3:1	Flatter slopes desirable
Grazing	2:1 or flatter	For ditches greater than 4 feet deep
	1½:1 or flatter	For ditches less than 4 feet deep
Dragline	½:1	Usually used on ditches with steep side slopes, greater than 4 feet deep
Blade equipment	3:1	Flatter slopes desirable
Turning plows	3:1	Flatter slopes desirable
Chemicals	Any	Use caution near crops
Burning	Any	

Velocity in Ditches

The ideal velocity for a ditch is one which causes neither scouring nor sedimentation. Since flows in most ditches are intermittent the velocity will fluctuate. Ditches are usually designed for the maximum design flow and the allowable average velocity in the ditch section. Where possible, the velocity in a ditch should increase going downstream to keep the sediment moving. This is seldom possible since the grade of the ditch conforms with the slope of the land and the steep grades usually are in the upper reaches. Table 14-2 contains recommended limiting velocities of design high water for various soils and materials, above which scour and erosion may take place. Raw, newly dug ditches may have a frictional value "n" less than will exist after some aging of the ditch takes place. Therefore, higher than design velocities may be expected in new ditches. When turf on the ditchside slopes is slow in developing, the limiting velocities may need to be reduced. An engineer should be consulted as to the adjustments that should be made.

Table 14-2 Permissible velocities

Soil Texture	Maximum Velocity ft./sec.
Sand and sandy loam (noncolloidal)	2.5
Silt loam (also high lime clay)	3.0
Sandy clay loam	3.5
Clay loam	4.0
Stiff clay, fine gravel, graded loam to gravel	5.0
Graded silt to cobbles (colloidal)	5.5
Shale, hardpan and coarse gravel	6.0

Determination of Ditch Velocity

Manning's formula is used in determining the average velocity in a ditch section. See Chapter 3 of this manual or refer to Hydraulic Tables, prepared by the Corps of Engineers.

Value of Coefficient of Friction "n"

The value of "n" is a factor in the formula for velocity. It indicates not only the roughness of the sides and bottom of the channel but also other types of irregularities of the channel, such as alignment and vegetation. The value of "n" is used to indicate the net effect of all factors causing retardation of flow. Its selection requires judgment in evaluating the factors of the material in which the channel is constructed, irregularity of surfaces of the ditch sides and bottom, variations in the shape and size of cross sections, obstructions, vegetation, and meandering of the ditch.

The National Engineering Handbook, Section 16, relates "n" values to the hydraulic radius and indicates that the "n" values decrease when the hydraulic radius increases. Table 14-3 gives the values of "n" recommended for design. These are the values which may be expected after aging and the "n" value actually occurring immediately after construction will be lower than the values given in the table.

Table 14-3 Value of "n" for drainage ditch design

Hydraulic radius	"n"
Less than 2.5	0.040 - 0.045
2.5 to 4.0	.035 - .040
4.0 to 5.0	.030 - .035
more than 5.0	.025 - .030

Ditch Bottom Widths

The type of machinery to be used for construction should be considered in the selection of ditch bottom widths. "V" type ditches are sometimes used when they are to be built with bulldozers or blade equipment. Flat bottom ditches frequently are designed when scrapers and draglines are to be used to construct the ditch. Depth of ditch and soil conditions affect the type of equipment used. Specified minimum bottom widths are often based on the types of equipment available.

Relationship Between Depth and Bottom Width

The most economical ditch section approaches that of a semicircle. As a general rule, a deep, narrow ditch will carry more water than a wide, shallow ditch of the same cross-sectional area. An excessively wide, shallow ditch tends to develop sand or silt bars which cause ditch meandering and bank cutting. A fairly deep, narrow ditch tends to increase velocities and to reduce siltation and meandering. The section selected is a matter of judgment, taking into account all factors involved. In some cases it may be necessary to sacrifice economy and hydraulic efficiency in the interest of ditch stability.

Calculation of Ditch Capacity

The volume of water passing a ditch cross section is calculated in cubic feet per second and is the product of the flow area cross section in square feet and the average velocity in the cross section expressed in feet per second.

The formula is: $Q = av$

Various curves and tables, all based on Manning's formula for velocity, have been prepared to determine ditch capacities. The "Hydraulic Tables" prepared by the Corps of Engineers are used also. See Exhibit 14-5 for SCS charts available for ditch design.

Ditch Berms

Adequate berms should be designed as required to provide roadways for maintenance equipment, to provide for work areas and to facilitate spoilbank spreading, to prevent excavated material from washing back into ditches, and to prevent sloughing of ditchbanks caused by placing heavy loads too near the edge of the ditch.

Spoil Banks

Spoil-bank leveling or shaping is a common and desirable practice. The degree of leveling, the placing of the spoil, and other practices related to the spoil are usually determined locally and specified in Technical Guides or State Standards and Specifications.

Bridges and Culverts

Design criteria for structures required for drainage ditches, or where irrigation canals cross drainage ditches, are specified by the authority responsible for the structure. The capacity requirement for these structures may be for floodflows which are much greater than the drainage requirement. Structures used on some township, private, and field roads may require only that the structure carry drainage flow. The following discussion is limited to this type of structure.

It is necessary that structures meet two requirements:

1. They must be of sufficient size and located so as to pass the design flow under the allowable head.

2. They must have adequate strength, size, and durability to meet the requirements of traffic.

Sufficient measurement should be made of existing structures to permit determination of their capacity. An existing structure may be considered adequate if it will pass the design drainage flow with a head which will cause no overbank flow above the structure. New culvert installations usually are designed for 25 percent more capacity than the ditch design as a factor of safety. A new bridge should be designed to span the ditch with the bottom of the stringers placed at least one foot above the hydraulic gradeline, and preferably with no piers located in the center portion of the ditch.

It is not necessary to break the hydraulic gradeline at structures as long as the head loss required to pass the design flow does not cause overbank flooding above the structure. Adjustment in the hydraulic gradeline should be made if such flooding will occur. The gradeline may be broken and dropped down at the structure an amount equal to the head loss.

Head loss through bridges where there is no restriction of the channel cross section is negligible. Head loss through culverts should ordinarily not exceed 0.5 foot. The head loss may be reduced by increasing the size of the structure.

Culvert Flow

There are several types of flow through culverts. Under some situations, detailed knowledge of hydraulics is necessary for their design. Two common situations where culverts may be used are:

1. Culverts flowing full with both ends submerged.

2. Culverts flowing full with unsubmerged or free discharge.

See Chapter 3 of this manual for design procedure.

Ditch Junctions

The bottom grades of ditches of approximately the same depth and capacity should be designed to meet at or near the same elevation. The bottom of a ditch of shallow depth and small capacity may be designed to meet a larger ditch at or near the normal or low flow elevation of the larger ditch. When a shallow ditch enters a much deeper ditch, a transition is designed. It is general practice to design the grade of the shallow depth upstream a distance of 10 to 100 feet on a zero grade at the elevation of the deeper ditch before beginning a transition. The transition should be on a nonerosive grade. This may vary from 0 to 1 percent depending upon site conditions.

Where the difference in the elevation of the ditch gradelines is considerable and transition grades seem impractical, a structure should be used to control the drop from the shallow ditch to the deeper ditch. See Chapter 6 of this manual.

Surface Water Inlets to Ditches

All drainage into mains and laterals should be through planned inlets, rather than letting the water enter the ditches at random and causing rills in the side slopes. This may be accomplished by installing chutes, drop spillways, pipe drop inlet spillways, culverts, or other suitable structures. See Figure 14-10 and Chapter 6 of this manual.

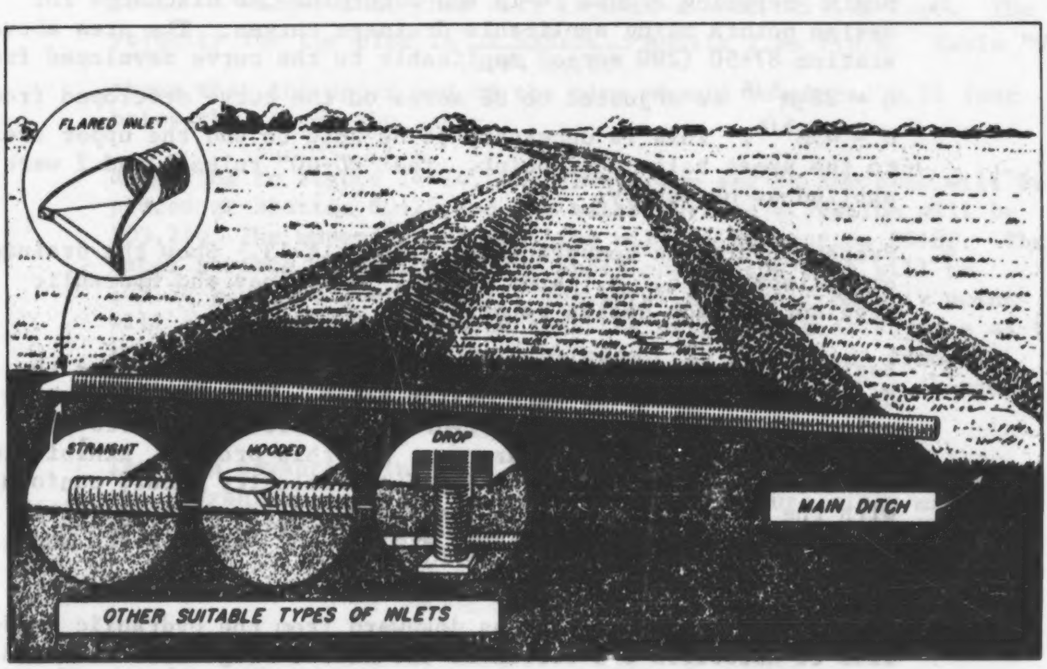


Figure 14-10 Types of surface water inlets

Swinging Watergates, Cattle Guards, and Ramps

Where applicable, watergates, cattle guards and ramps should be used on open ditches to aid in pasturing and to protect the ditches. See Exhibit 14-7 for a typical plan of a watergate.

Ditch Design Problem

Example - Open Ditch Design

Given: Drainage area - 1450 acres (Figure 14-11)
Apply $Q = 22\frac{1}{2}M^{5/6}$ curve on 200 acres
Apply $Q = 45M^{5/6}$ curve on 1250 acres
Profile of ditch (Figure 14-12)
Side slopes 2:1
Value of "n" - .045
Minimum bottom width - 4 feet.

Required: Design of ditch for surface water removal.

Solution:

1. Locate control points and hydraulic gradeline as shown in Figure 14-12.

2. Draw subdivides for reaches and other design points (Figure 14-11) and determine their drainage areas.

3. Begin preparing Figure 14-13 and determine the discharge for design points using applicable drainage curves. The area above station 87+50 (200 acres) applicable to the curve developed from $Q = 22\frac{1}{2}M^{5/6}$ is adjusted to 86 acres on the curve developed from $Q = 45M^{5/6}$. This is necessary to be able to add the upper area to the areas below this point. The "20-40" rules 1 and 2 were applied as necessary.

4. Prepare hydraulic computations, Figure 14-13. Show the drainage area, discharge c.f.s., side slopes, "n" values and hydraulic gradient at each design point.

5. Begin with a minimum bottom width of 4 feet and determine the depth and velocity for each design point. This may be done by using the Corps of Engineers Hydraulic Tables, or curves and tables prepared for this purpose. For this problem, Exhibit 14-6 was used. The bottom width, depth and velocity should conform with the previously specified requirements for drainage ditch design. If they do not, assume a different bottom width and recalculate.

6. Measure the calculated depths downward from the hydraulic gradeline to establish the bottom of the ditch. Figure 14-14 shows

there are drops at stations 25+00 and 72+50 and a rise at station 50+00. This rise is eliminated by continuing the upstream cross section until it blends with the downstream cross section. The bottom is satisfactory for the design regardless of the drops; however, the drops could be eliminated by varying the bottom width. If drops are less than one foot and are staked as the design shows, nature will soon eliminate them. Most machine work is not so accurately done that small drops will be detrimental to the ditch. For larger drops, the design may be changed or a transition section installed at the drops.

7. Bridge at station 25+00. - Field information on this existing bridge indicates that the area of flow of the new ditch will not be reduced to any appreciable amount and there will be no head loss åt the bridge. Therefore, the hydraulic gradient will not be changed at that point.

8. A new crossing is to be established at station 80+50. (Q = 18 c.f.s.) Assume that two 24-inch concrete pipes, 60 feet long with beveled lip will be installed. Determine the head loss.

   Solution by Exhibit 14-4. - The tailwater depth is 26 inches and the pipe will have a submerged outlet. Table C-1 gives a value of C as 0.75 for a 24-inch concrete pipe, beveled lip entrance. One-half of 18 c.f.s. is 9 c.f.s. for each 24-inch pipe.

$$\frac{9.0}{.75} = 12$$

   Table "A" shows that this will require a head of 0.23 foot. The velocity for the pipe is $\frac{9 \text{ c.f.s.}}{3.14 \text{ sq.ft.}}$ equals 2.86 f.p.s. Table "F" shows that the upper end of the pipe should be placed 0.14 foot below the top of the water.

   Referring to Figure 14-14, the downstream end of the pipe will be placed at station 80+20 and the water surface elevation will be 103.21. The upper end of the pipe will be at station 80+80. The water surface elevation at the upper end of the pipe will be 103.24 plus 0.23, or 103.47. The water surface from this point will curve upstream and intersect the original water surface as located several hundred feet upstream. It is evident from the profile that this change in water surface will cause no damage upstream.

   The main advantage in using this method of design is that once the hydraulic gradeline is set, various structure sizes may be selected without changing the tailwater elevation and only the backwater curve is involved.

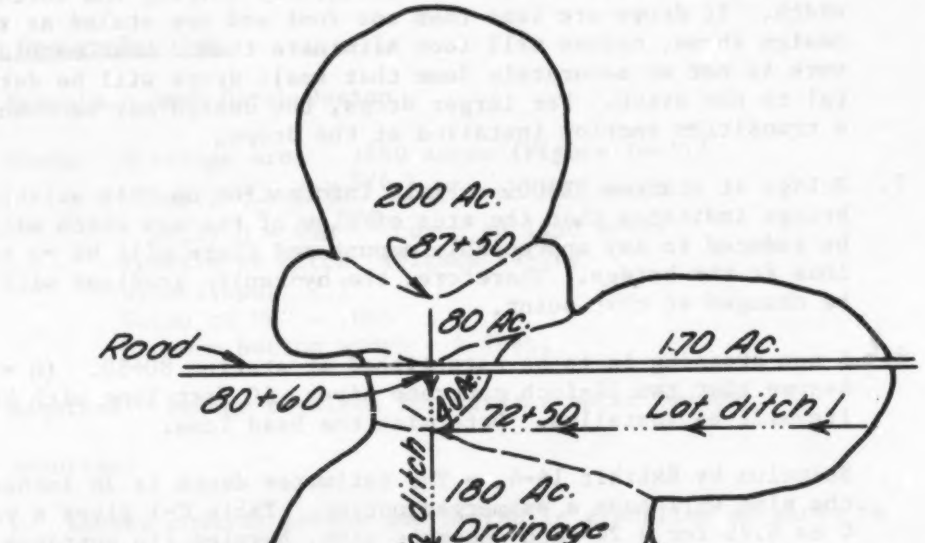

200 Ac.
87+50
80 Ac.
1.70 Ac.
Road
80+60
10 Ac.
72+50
Lat. ditch 1
180 Ac.
Main ditch
Drainage divide
50+00
200 Ac.
Lat. ditch 2
35+00
160 Ac.
100 Ac.
Road
25+00
120 Ac.
200 Ac.
0+00
outlet ditch

Figure 14-11 Watershed sketch problem

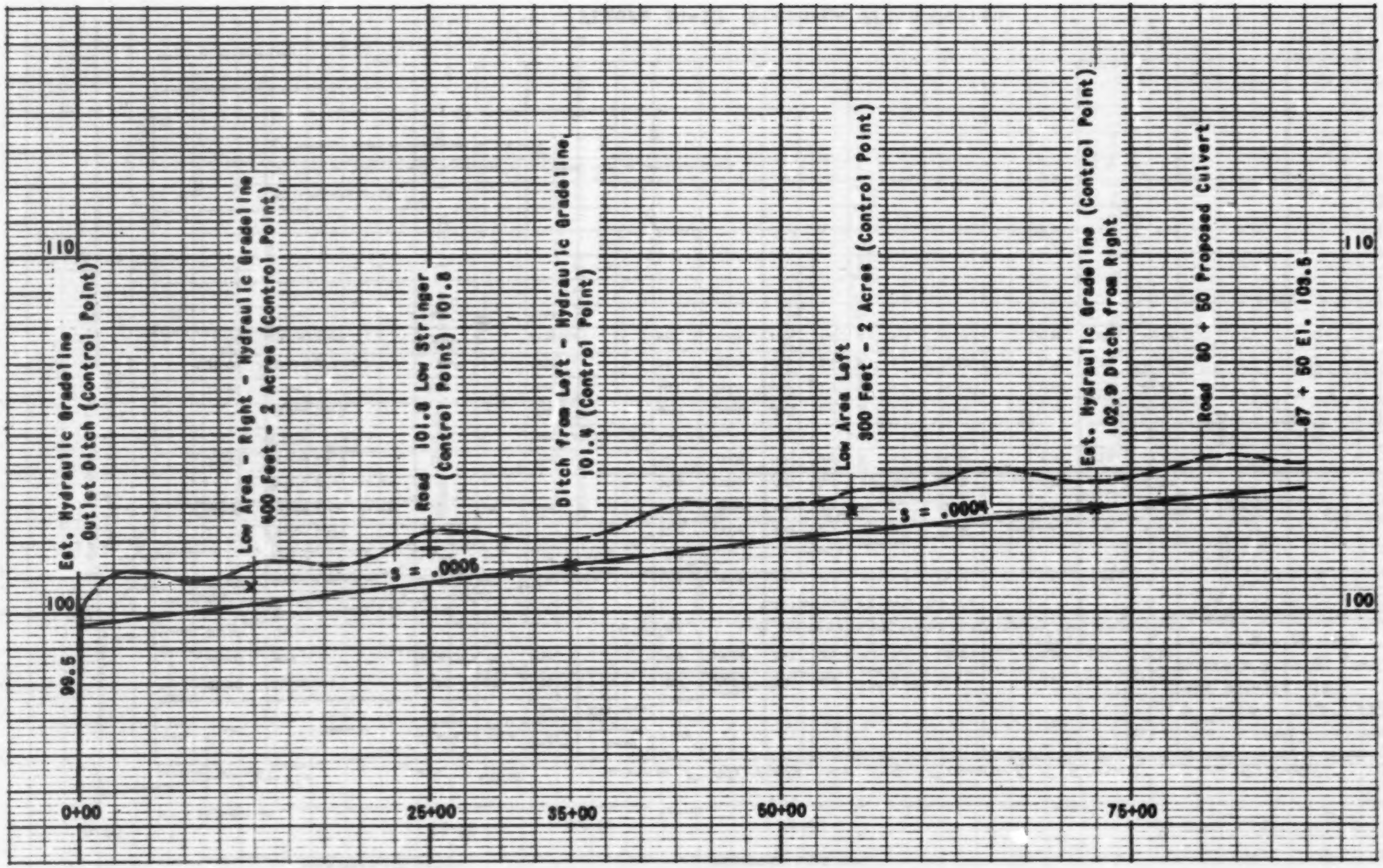


Figure 14-12 Profile ditch with hydraulic gradient

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

DRAINAGE DITCH DESIGN

SOIL CONSERVATION DISTRICT MIDDLE RIVER WORK UNIT PLUMNELLY, ARKANSAS

COOPERATOR HARPER DRAINAGE GROUP LOCATION PERSIMMON LAKE ARK. PAGE 1 OF 1

SCD AGREEMENT NO. ACP NO. FIELD NO.

DESIGNED BY John Blue DATE 6/3/68 CHECKED BY *E. Michels* DATE *6-4-68* APPR'D BY *E. C. Short* DATE *6-8-68*

Ditch No.	Sta.	Location	Area Acres	Drain. Curve	Equ. A. 45	Runoff		Req'd Q	s	n	s/s	b	d	A	P	r	v	Des'nd Q	H.G. Elev.	Actual		
					Curve	% Area	M'thd													Depth	Bottom Elev.	Bottom Width
Main No. 1	87+50	Upper end	200	22½	86			8.4	.0004	.045	2:1	4 1/	2 2/	16.0		1.24	0.76	12.2				
	80+60	Road	80	45	166			14.5	.0004	.045	2:1	4	2.2	18.48		1.34	0.80	14.8				
	80+60	Culvert					Q+25%	18.1	2–2[illegible]" concrete pipe with beveled lip entrance, 50' long, operating under													
									0.23 foot head will carry 18.0 c.f.s.													
	72+50	Above Lat 1	40	45	206			17.0	.0004	.045	2:1	4	2.4	21.12		1.43	0.84	17.7				
		Lat 1	170	45	170	45.2	1	15.0														
		Below Lat 1						3[illegible].0	.0004	.045	2:1	4	3.2	33.28		1.82	0.98	32.8				
	50+00	Above grade change	180	45	556			39.0	.0004	.045	2:1	4	3.6	40.32		2.01	1.05	42.4				
		Below grade change						39.0	.0005	.045	2:1	4	3.4	36.72		1.91	1.14	41.7				
	35+00	Above Lat 2	200		756			52	.0005	.045	2:1	4	3.8	44.08		2.10	1.21	53.3				
		Lat 2	160		160	17.5	2	14														
		Below Lat 2			916			62	.0005	.045	2:1	6	3.8	51.68		2.25	1.26	65.12				
	25+00	Road	100		1016			66	.0005	.045	2:1	6	3.9	53.82		2.29	1.28	68.89				
	20+00	Drainage area	120		1136			74	.0005	.045	2:1	6	4.1	58.22		2.39	1.32	76.85				
	0+00	Outlet ditch	200		1336			82	.0005	.045	2:1	6	4.3	62.78		2.49	1.36	85.38				
		Total	1450		1336																	

*C in formula $Q=CM^{5/6}$

1/ Minimum bottom width recommend for equipment used to construct ditch.

2/ Minimum depth recommended for the area.

USDA-SCS-FORT WORTH, TEX. 1968

Figure 14-13 Drainage ditch design

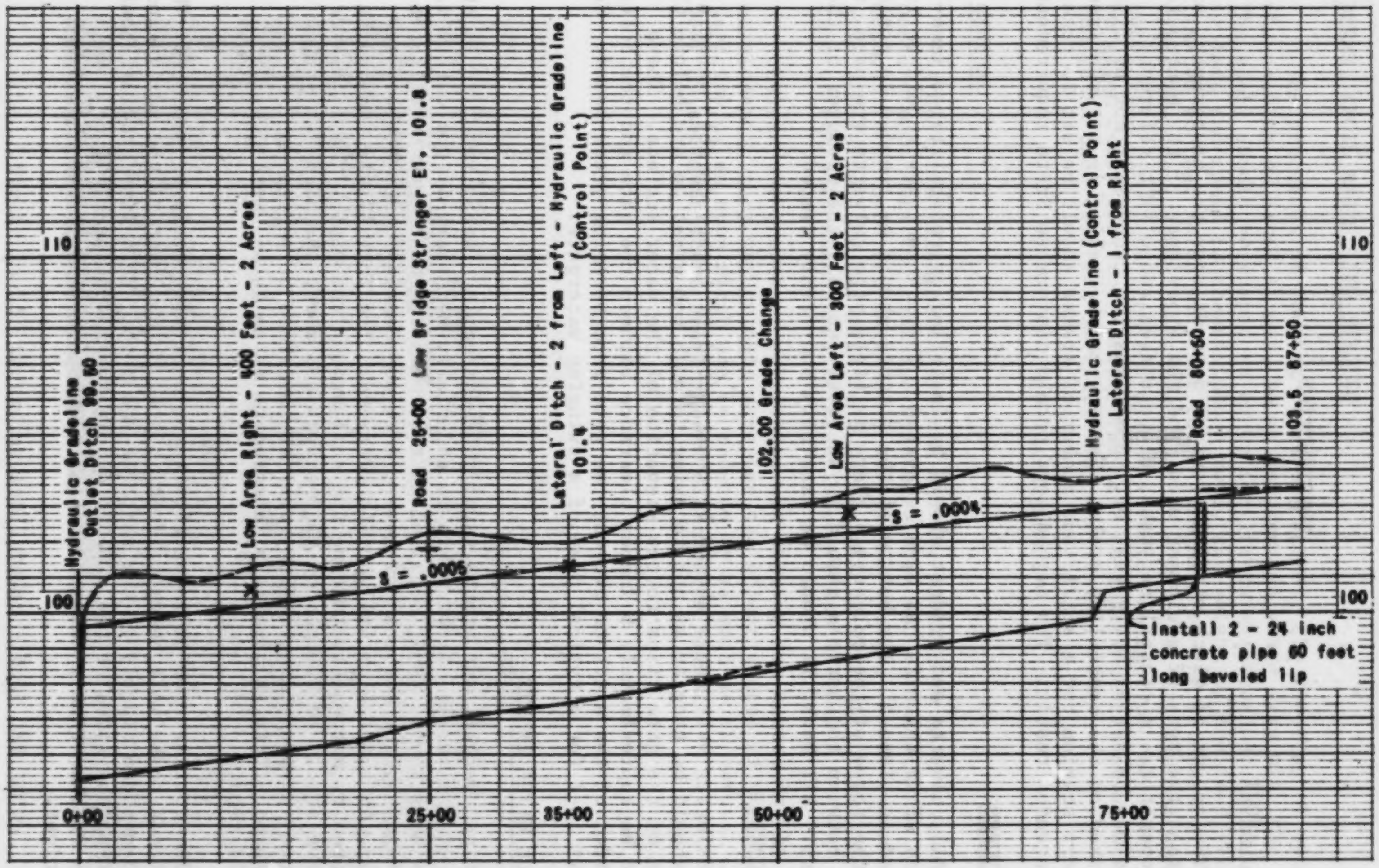


Figure 14-14 Design profile

5. CONSTRUCTION

DITCH LAYOUT

The amount of ditch staking required depends upon the topography, size of ditch, the type of equipment used, and the experience of the contractor or cooperator. A centerline stake, slope stakes and offset reference stakes may be set at every station. Sometimes the centerline cut or fill is marked on the centerline stake. In many cases staking is not required at every station but a sufficient number of stakes should be set to obtain the intended result. The method used should conform to State requirements.

STRUCTURES

All culverts and bridges should be installed or rehabilitated immediately after the site has been excavated. These structures should be installed as planned. The bottom of the ditches should be rounded to conform with the shape of the culverts. Where multiple pipe culverts are used, the space between the barrels should be at least one-half the diameter of the culvert. All backfill should be carefully and firmly tamped.

WATERGATES

Swinging watergates should be constructed of light, durable material. They should be hung so as not to swing through too great an arc before the bottom of the gate rises to the elevation of the water surface. There should be approximately 6 inches clearance between the gate and the bottom and sides of the ditch to prevent the gate from becoming grass bound. See Exhibit 14-7 for a typical plan of a swinging watergate.

SURFACE WATER INLETS

Pipe overfall structures usually discharge into areas recessed in the banks of the outlet ditch. This is especially necessary if the outlet is a flowing stream. When installed in this manner, the structure will not be damaged by the movement of water, ice, and debris in the outlet, and the flow in the outlet will not be retarded. The installation should be completed by adequately tamping the soil around the pipe. The fill over the pipe should be brought up high enough and along the pipe far enough to force any possible overflow water to the sides to prevent a failure by washout. This is generally referred to as an island method of installation.

The installation of inlet structures on fills should be avoided. The pipe needs to be well bedded. That is, the bottom part of the excavation should conform closely to the shape of the pipe. This fine grading should extend up the sides of the pipe to a point where the backfill can be easily reached with a hand or mechanical tamper. All joints should be watertight.

BERMS, SPOIL BANKS, AND SEEDING

The practices of leaving berms on ditches, the leveling of spoil, and the seeding of ditch slopes, berms and leveled areas vary with the locality. The spoil should be shaped so as to facilitate maintenance. When no berm is left and spoil is shaped into a road, the height of the road should be limited to that which will not cause sloughing of the ditchbanks. In all cases the spoil should be shaped in such a way that the minimum amount of water will flow back into the ditch. Erosion control of the spoil should be given consideration. State Standards in regard to the above items should be used (Figures 14-15, 14-16, and 14-17).

6. MAINTENANCE

GENERAL

A definite maintenance program and the methods to be used should be decided upon when the drainage system is planned, because the maintenance methods to be used can materially affect the design. A good maintenance plan should include the practices to be used as well as the approximate time of the year when specific practices are applicable.

Unless the growth of vegetation and silting are controlled by regular maintenance, they may quickly decrease the effectiveness of the ditch. The capacity of an open ditch can be reduced by as much as 50 percent in one year by sediment and a heavy growth of weeds or brush.

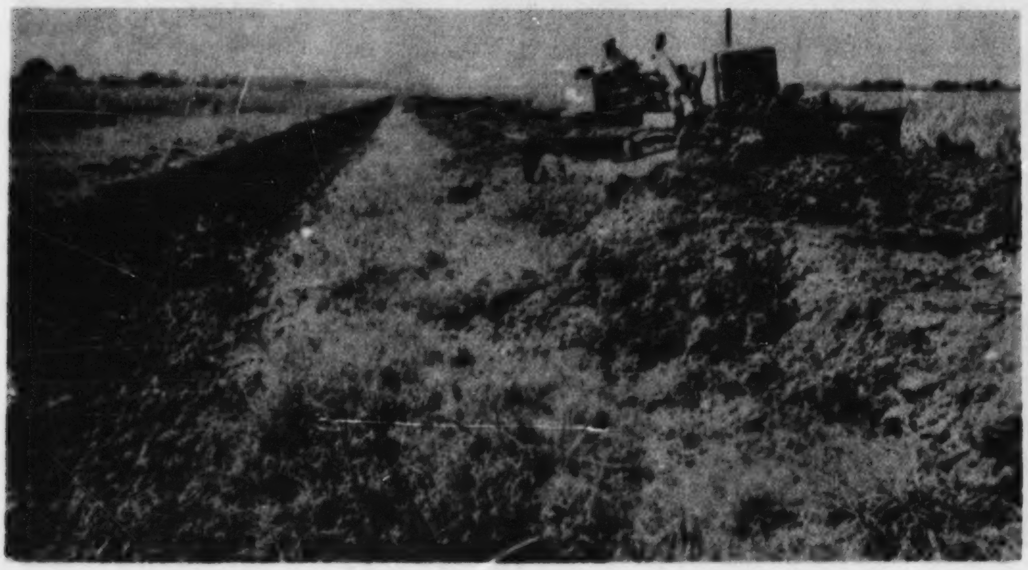


Figure 14-15 Spreading spoil banks - Note the berm.

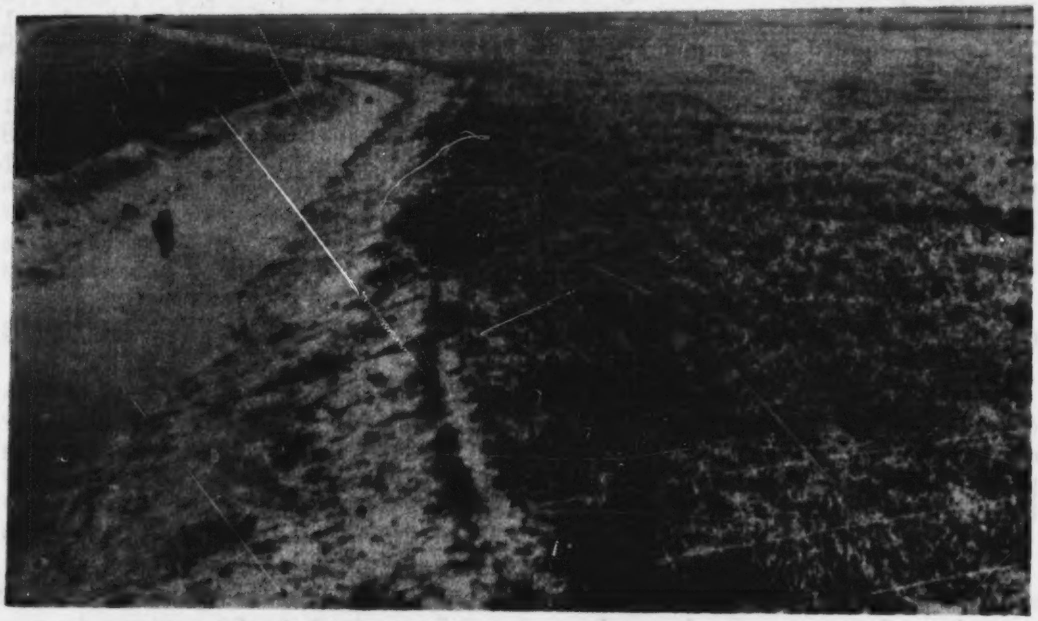


Figure 14-16 Main drainage ditch with spoil banks spread

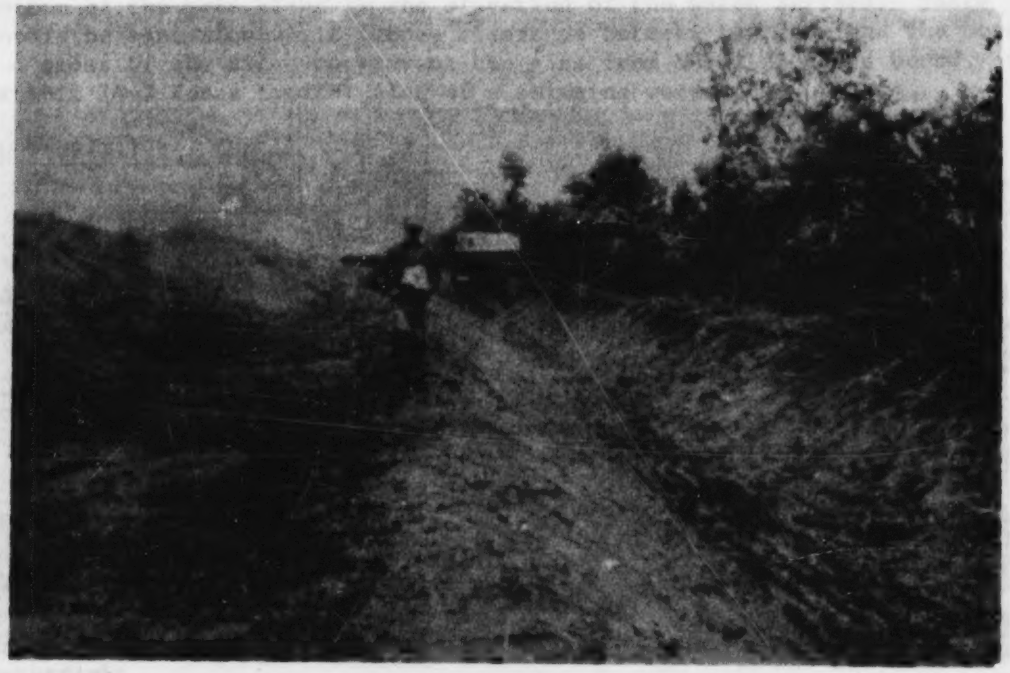


Figure 14-17 Seeding newly constructed main drainage ditch. Dragline oiler using contractor's cyclone seeder.

GRAZING

Regulated grazing is an effective and economical method of controlling vegetation in drainage ditches. Some ditches maintained by grazing have been kept in good condition for many years. Stock should not be allowed to overgraze the ditches, nor should ditchbanks be grazed when saturated. Hogs should be kept out of ditches at all times.

If ramps are provided at intervals, cattle may get in and out of a ditch without damage to the ditchbanks. The ramps should be on a slope of 4:1 or flatter and at least 10 feet wide.

MOWING

Mowing to control vegetation on spoil banks, berms, and ditches is both economical and effective if the side slopes are not too steep. For safety, side slopes on which farm tractors are to be operated should be made 3:1 or flatter; 4:1 slopes are preferred (Figures 14-18 and 14-19).

BURNING

Burning in winter or early spring, when the vegetation is dry and the ground is wet is helpful in controlling undesirable vegetation in drainage ditches. Care must be taken not to destroy bridges, fences, or other property.

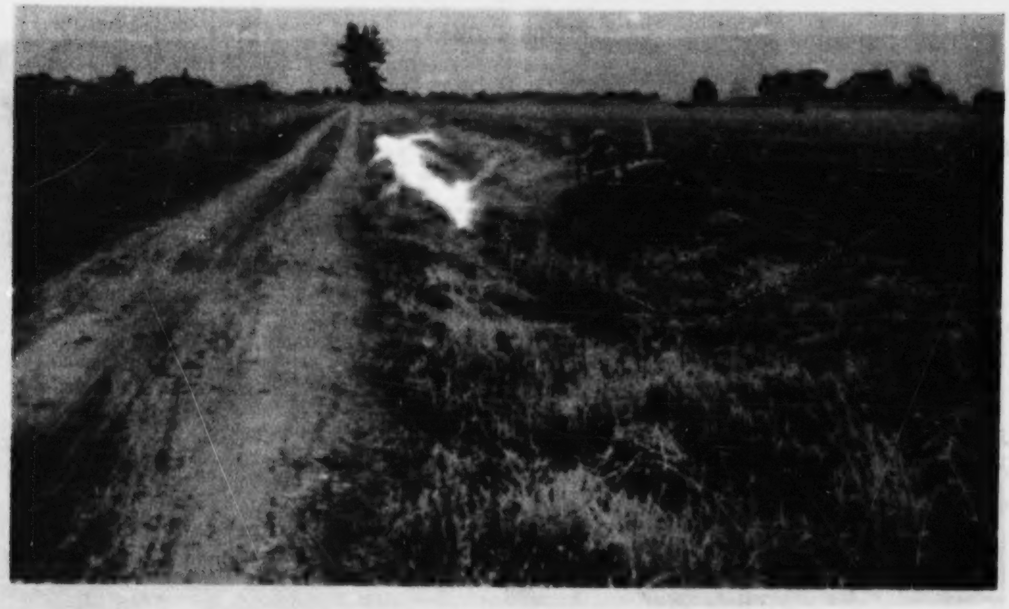


Figure 14-18 Maintenance by mowing

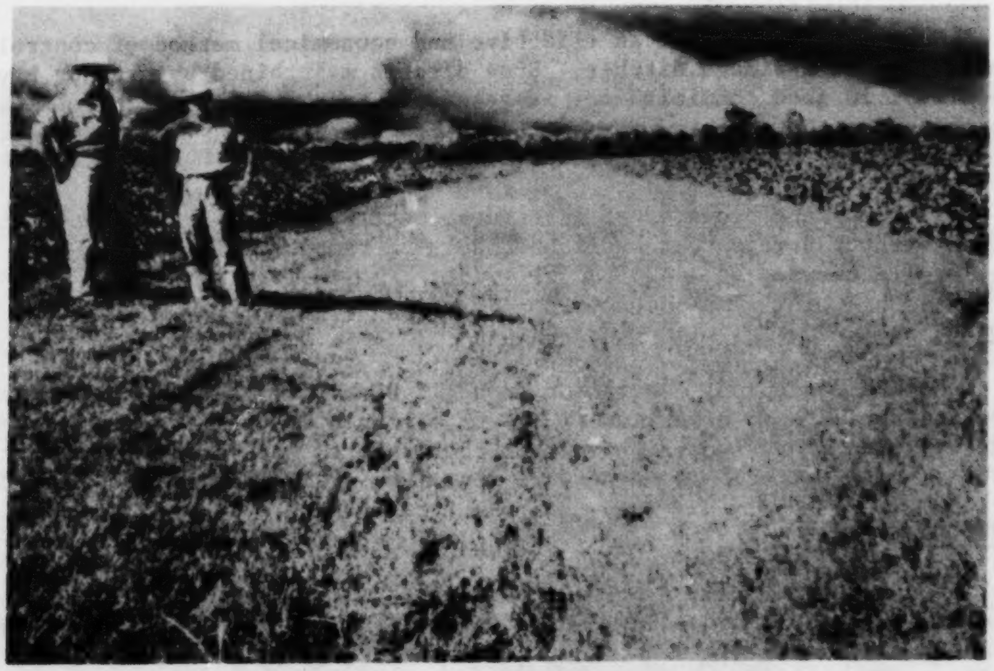


Figure 14-19 Lateral drainage ditch well maintained by mowing 3 to 5 times a year

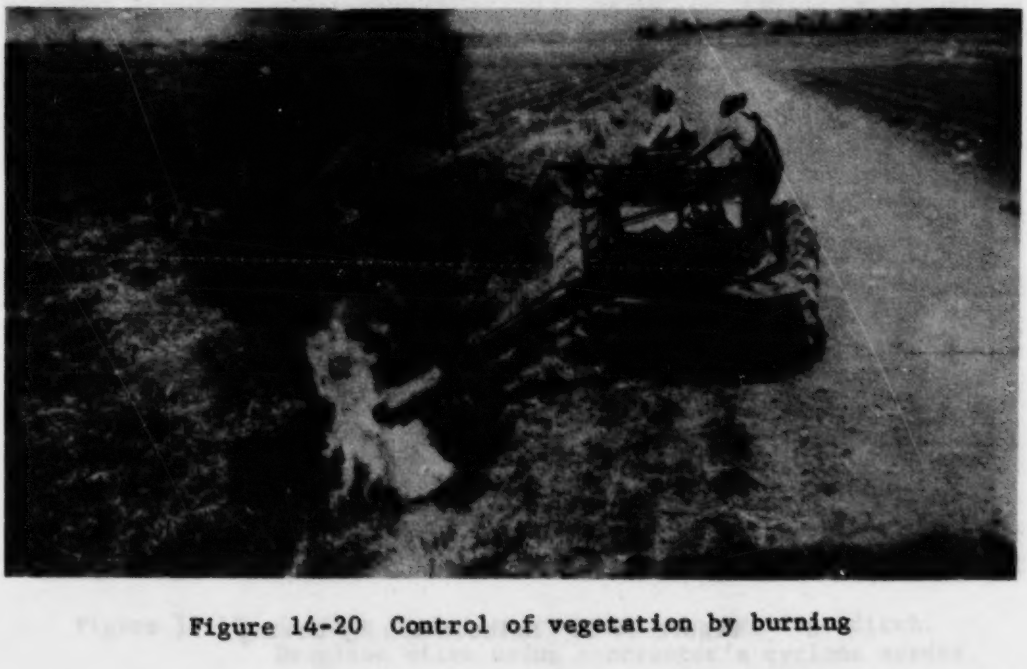


Figure 14-20 Control of vegetation by burning

Some farmers use oil burners to control vegetation by regular burning during growing season. Usually, the first burning will kill the green vegetation and stunt the growth. A second burning about two weeks later is quite effective because vegetation killed in the first burning leaves much dry material which will burn readily. It is, of course, important to keep the fire away from crops in adjoining fields and structures near the ditch (Figure 14-20).

CHEMICALS

Chemicals to control undesirable vegetative growth have produced some excellent results and are used by farmers and drainage enterprises. Caution should be used in their application to prevent damage from the drifting chemicals. Broadleaf crops and some truck crops are particularly susceptible to damage. Information on appropriate chemicals usually may be obtained from local dealers. Major chemical companies have prepared considerable information relative to usage of specific products.

For guidance in the use of chemicals on common ditchbank weeds, refer to Section 16, National Engineering Handbook, or local Technical Guides. Some of the states have prepared technical guides and herbicide manuals in cooperation with other agencies. The most up-to-date information available, including data on new herbicides, should be followed.

Spraying large ditches by airplane or helicopter has proven economical and effective in many areas.

State laws governing use of herbicides should be followed.

7. LAND FORMING

Land forming refers to the changing of the land surface to insure the orderly movement of surface water. Land smoothing and land grading are methods used in surface drainage to improve the effectiveness of the drainage system.

LAND SMOOTHING

Removing small irregularities on the land surface by use of special equipment is termed land smoothing, which does not require a grid survey. This includes operations ordinarily classed as rough grading.

Land smoothing is an important practice for good surface drainage. It eliminates minor differences in field elevations and shallow depressions. It will not change the general contour of the ground surface appreciably. However, better drainage is obtained, usually with fewer surface ditches, and more efficient operation of farming equipment is possible. After smoothing, less ice crusting occurs in winter months in areas where this is a problem.

Soils to be smoothed must have a profile which will allow small cuts. Except for isolated spots handled by prior rough grading, land smoothing operations seldom involve cuts and fills exceeding 6 inches.

High and low spots on the areas to be smoothed usually are visible to the eye without use of an engineer's level. However, sufficient spot elevations should be taken and adequate planning done to assure that water will move readily and without ponding to the field ditches and laterals.

Land smoothing is accomplished best by special equipment, such as the landplane or leveler which can work efficiently to tolerances of one-tenth foot or less. This degree of accuracy is necessary to remove irregularities from very flat land. Rough grading for land smoothing can be done with farm tractors and scrapers or a landplane. In making cuts, removing all topsoil from any area should be avoided. It would be better to take thin layers from a larger area. Where fills from rough grading exceed 6 inches, allowance for fill shrinkage should be made. The allowance is related to types of soil and soil conditions. Allowances may be given in the local technical guides. Or, final smoothing operations may be deferred until compaction or natural settlement of such areas has taken place.

DRAINAGE LAND GRADING

General

Land grading for drainage is precision shaping of the surface of the land so that each row or plane is graded throughout its length to field ditches or other suitable outlets.

The land is graded so that rows will carry surface runoff without overtopping. It varies from irrigation land leveling in that row or plane grades may be varied within erosive limits to provide drainage with the least amount of grading. Local Technical Guides give guidance on land grading for drainage.

Planning

Topographic surveys should be made for planning the surface grading and the auxiliary drainage system. National Engineering Handbook, Section 15, Chapter 12, "Land Leveling" provides information on surveys, design methods, construction and maintenance. Local Technical Guides also will provide information and applicable criteria.

Construction

Land smoothing is accomplished by land levelers or landplanes. The length of most land smoothing equipment varies from 20 to 50 feet, with the longer length giving a more refined job. The large levelers or planes with overall span length of approximately 50 feet may require a crawler-type tractor for power. Those with span lengths of from 20 to 30 feet may be pulled with the ordinary wheel-type farm tractor. These smaller machines can do a good job on any field but require more trips over the field than the large machine.

To facilitate smoothing operations, the ground surface should be plowed or disked prior to smoothing and should be free of vegetation and trash. Plowing facilitates the movement of the dirt by the leveler and mixes crop residues into the soil, thus preventing vegetation from collecting on the leveler blade. If the area is in sod, it should be plowed 3 to 6 months ahead of smoothing operations or farmed in a cultivated crop one year previous to smoothing.

The roughness of the field and the number of minor depressions determine the number of passes of smoothing equipment over the field required to produce a smooth field. At least 3 passes of the landplane or leveler should be made in different directions. These consist of one pass along each diagonal with the last pass generally in the direction of cultivation. On fields that require fills in the larger depressions, settlement is apt to occur the first year after smoothing. On relatively flat fields, this settlement may produce pockets that will collect and hold water. The field should be observed closely the year after smoothing, and if such pockets have developed the field should be given at least 3 more passes of the smoothing equipment with special emphasis on the settled areas.

Where it is necessary to expose subsoil, additional soil treatment should be given to these exposed areas. Unless the subsoil is very low in fertility, the exposed areas can be brought back to normal production in a short time. The exposure of small areas of subsoil is not a serious situation when considering the entire field as a unit. Generally, it is much better to expose small areas of subsoil than to have numerous pockets that will hold water after rains and cause greater reductions in crop yields.

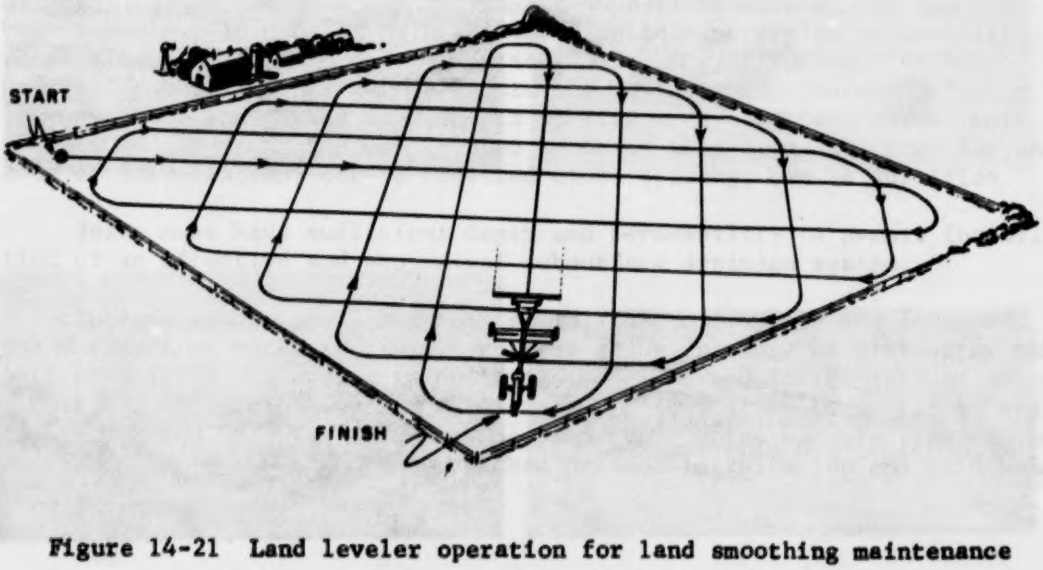


Figure 14-21 Land leveler operation for land smoothing maintenance

MAINTENANCE

Land preparation practices require year-to-year maintenance to retain their efficiency. Once the field has been properly prepared to achieve good surface drainage, the ordinary crop cycle involving plowing, planting, cultivating and harvesting--to say nothing of the wind and water action during the course of the year--will disturb the surface enough to impound water and cause crop damage. The cropping cycle irregularities, such as implement scars, backfurrows, and dead furrows need to be erased before each crop is planted. Therefore, each year a leveler or plane should be operated over the area at least twice. This operation also will care for settlement in the fill areas and provide a base for a good seedbed.

A good way to cover a field with a leveler for maintenance is shown in Figure 14-21. With this diagonal method, it is possible to cover most of the field with 2 passes of the leveler in the minimum amount of time. Farmers report that this method reduces the maintenance time by about one-fourth. Figure 14-22 shows several different kinds of landsmoothing equipment.

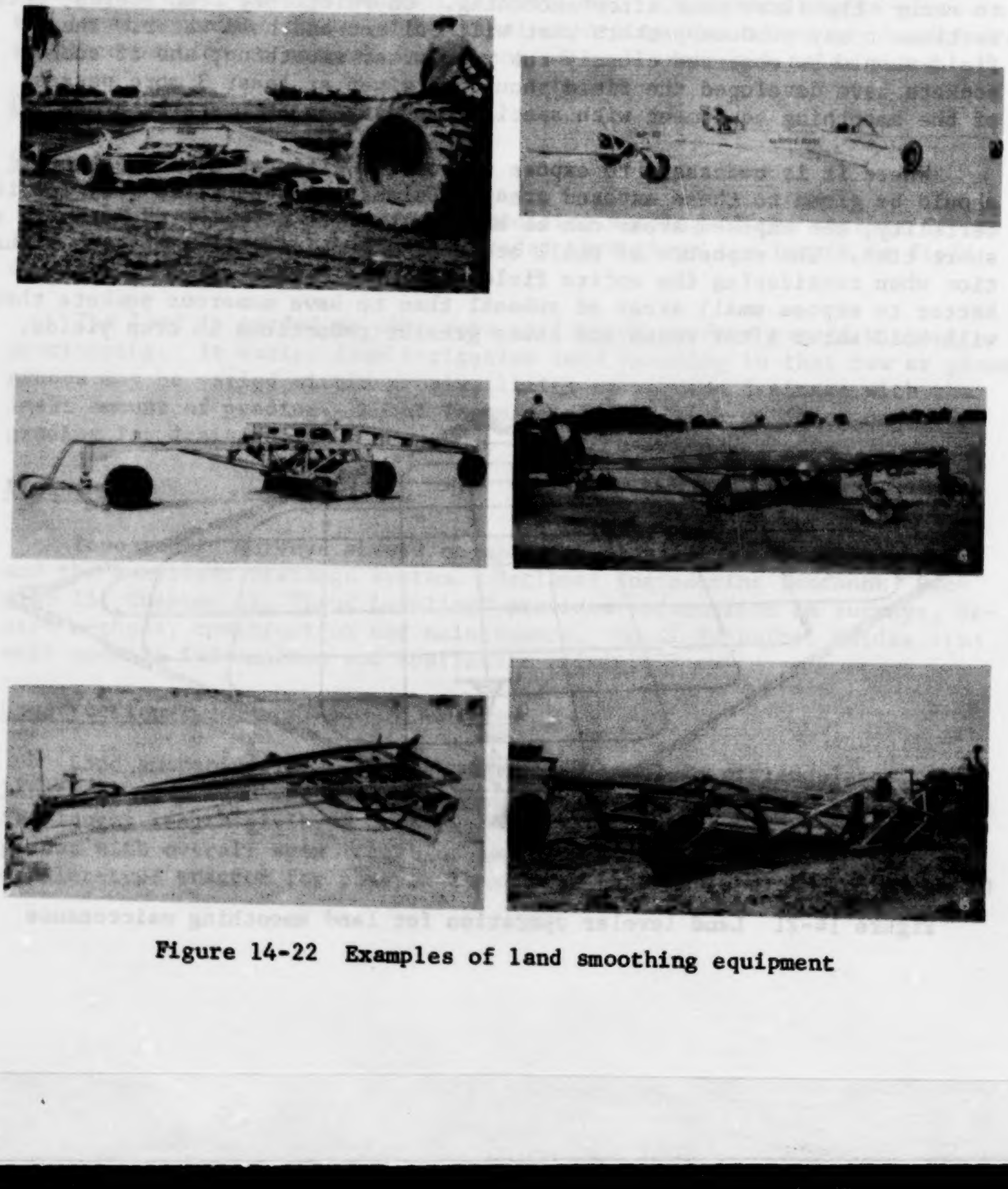


Figure 14-22 Examples of land smoothing equipment

PART II - SUBSURFACE DRAINAGE

1. GENERAL

Subsurface drainage removes free water from the soil and subsoil below the surface of the ground and lowers the water table for better growing conditions for crops. The function of subsurface drainage in the humid area and in irrigated areas is to prevent and eliminate high water tables and waterlogging of the soil. Additional functions in irrigated areas are to prevent excess salt and alkali accumulation, and to remove existing accumulations. Subsurface drainage may be accomplished by various types of buried drains, by mole drains, and open ditches.

PLANS

A plan should be made of every subsurface drainage layout. Requirements for the plan in regard to the size and the detail vary in different areas. However, basic information required for the construction should be contained in the plan. Figure 14-23 is an example of a plan.

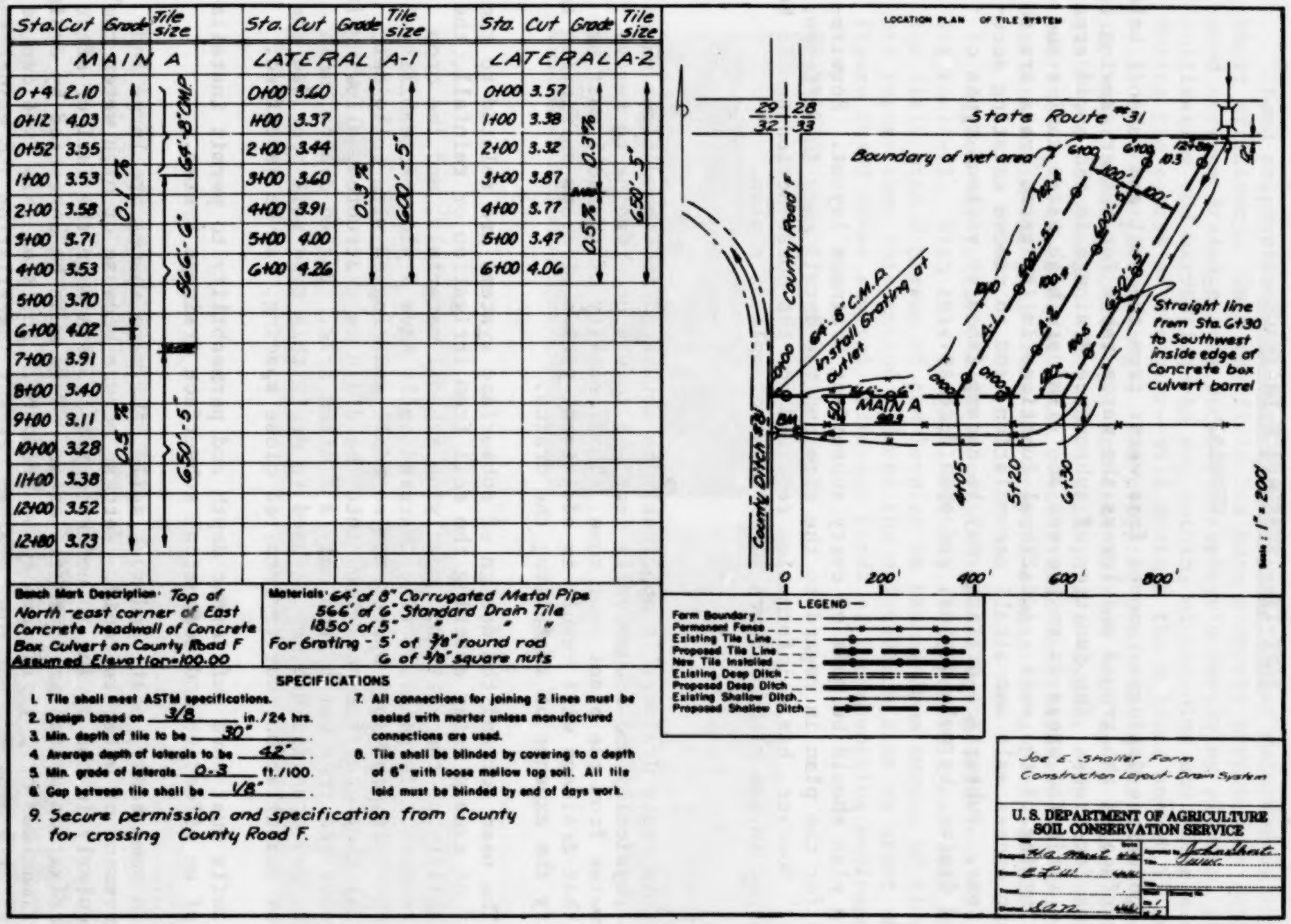
SOILS

Subsurface drainage is applicable to saturated soil conditions where it is physically and economically feasible to use underdrains to remove free water from the plant root zone. The fertility of the soil must be such that drainage will result in additional yields of crops sufficient to justify the expense of installing the drains.

The need for and the design of subsurface systems are related to the amount of excess water entering the soil from irrigation or rainfall, the permeability of the soil and underlying subsoil materials, and the crop requirements. In general, fine textured soils have a slow permeability. In such soils, the pore spaces are so small and clogged with colloidal material that gravitational flow into the drain is obstructed, allowing it to remove the free water from only a limited area. Buried drains, mole drains, and open ditches may be used to drain this type soil provided the cost of installation, due to required close spacing, can be justified.

Soils must have sufficient depth and permeability to permit installation of an effective and economical subsurface drainage system.

In some sandy, peat, and muck soils, the pore spaces are large and the movement of water is rapid. Wetness occurs because of high water table, particularly in the spring in nonirrigated areas and in the fall or after the irrigation season in irrigated areas. This must be corrected by drainage if maximum crop yields are to be produced. Soils of this type can be successfully drained, but many of them present installation and maintenance problems.



Sta.	Cut	Grade	Tile size
MAIN A			
0+4	2.10	0.1%	64'-8" CMP
0+12	4.03		
0+52	3.55		566'-6"
1+00	3.53		
2+00	3.58		
3+00	3.71		
4+00	3.53		
5+00	3.70		
6+00	4.02	0.5%	
7+00	3.91		650'-5"
8+00	3.40		
9+00	3.11		
10+00	3.28		
11+00	3.38		
12+00	3.52		
12+80	3.73		

Sta.	Cut	Grade	Tile size
LATERAL A-1			
0+00	3.60	0.3%	600'-5"
1+00	3.37		
2+00	3.44		
3+00	3.60		
4+00	3.91		
5+00	4.00		
6+00	4.26		

Sta.	Cut	Grade	Tile size
LATERAL A-2			
0+00	3.57	0.3%	650'-5"
1+00	3.38		
2+00	3.32		
3+00	3.87	0.5%	
4+00	3.77		
5+00	3.47		
6+00	4.06		

Bench Mark Description: Top of North-east corner of East Concrete headwall of Concrete Box Culvert on County Road F
Assumed Elevation=100.00

Materials: 64' of 8" Corrugated Metal Pipe
566' of 6" Standard Drain Tile
1850' of 5" " " "
For Grating - 5' of 3/8" round rod
6 of 3/8" square nuts

SPECIFICATIONS

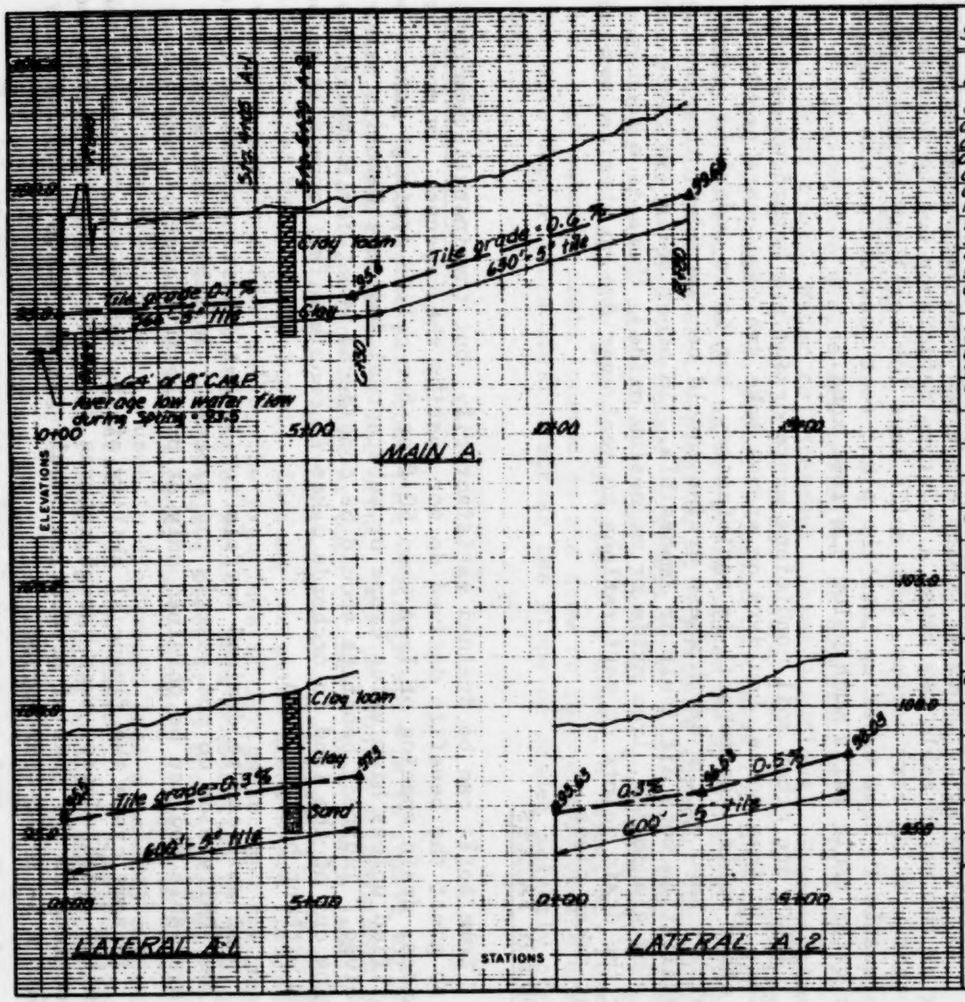
1. Tile shall meet ASTM specifications.
2. Design based on 3/8 in./24 hrs.
3. Min. depth of tile to be 30".
4. Average depth of laterals to be 42".
5. Min. grade of laterals 0.3 ft./100.
6. Gap between tile shall be 1/8".
7. All connections for joining 2 lines must be sealed with mortar unless manufactured connections are used.
8. Tile shall be blinded by covering to a depth of 6" with loose mellow top soil. All tile laid must be blinded by end of days work.
9. Secure permission and specification from County for crossing County Road F.

Joe E. Shaller Farm
Construction Layout - Drain System

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

LOCATION PLAN OF TILE SYSTEM
29 28
32 33
State Route #31
County Road F
County Ditch #31
Boundary of wet area
64'-8" C.M.P.
Install Grating at outlet
0+00
566'-6"
MAIN A
BM
50'
98.3
A-1
A-2
600'-5"
650'-5"
101.0
100.9
100.5
102.2
103
6+00
12+80
100'
4+05
5+20
6+30
Straight line from Sta. 6+30 to Southwest inside edge of Concrete box culvert barrel
0
200'
400'
600'
800'
Scale: 1" = 200'
— LEGEND —
Farm Boundary
Permanent Fence
Existing Tile Line
Proposed Tile Line
New Tile Installed
Existing Deep Ditch
Proposed Deep Ditch
Existing Shallow Ditch
Proposed Shallow Ditch

Figure 14-23 Tile plan and layout


ELEVATIONS
STATIONS
MAIN A
0+00
5+00
10+00
15+00
Clay loam
Clay
Tile grade 0.1%
366'-5" tile
Tile grade = 0.6 %
630'-5" tile
95.8
99.68
64' of 8" C.M.P.
Average low water flow during Spring = 93.5
LATERAL A-1
0+00
5+00
Clay loam
Clay
Sand
Tile grade = 0.3%
600'-5" tile
95.5
97.3
LATERAL A-2
0+00
5+00
0.3%
0.5%
600' - 5" tile
95.63
96.53
98.03
105.0
100.0
95.0

Sta.	B.S.	H.I.	F.S.	* Elev.	Tile Bottom	Remarks
		MAIN	A			
B.M.				100.0		
.	4.84	104.84				
0+00			11.31	93.53		Water level
0+12			5.80	99.04	95.01	Ditch bank
0+40			4.60	100.24		℄ Road
0+50			7.52	97.32		Road ditch
0+52			6.24	98.60	95.05	East side ditch
1+00			6.21	98.63	95.1	
2+00			6.06	98.78	95.2	
3+00			5.83	99.01	95.3	
4+00			5.77	99.07	95.4	
5+00			5.64	99.20	95.5	
6+00			5.22	99.62	95.6	
7+00			4.73	100.11	96.2	
T.P.	5.98	106.31	4.51	100.33		
8+00			6.11	100.20	96.8	
9+00			5.80	100.51	97.4	
10+00			5.03	101.28	98.0	
11+00			4.33	101.98	98.6	
12+00			3.59	102.72	99.2	
12+80			2.90	103.41	99.68	
T.P.	5.62	105.82	6.11	100.20		
		LATERAL		A-1		
0+00			6.72	99.10	95.5	0+00 = 4+05
1+00			6.65	99.17	95.8	
2+00			6.28	99.54	96.1	
3+00			5.82	100.00	96.4	
4+00			5.21	100.61	96.7	
5+00			4.82	101.00	97.0	
6+00			4.26	101.56	97.3	
		LATERAL		A-2		
0+00			6.62	99.20	95.63	0+00 = 5+20
1+00			6.51	99.31	95.93	
2+00			6.27	99.55	96.23	
3+00			5.42	100.40	96.53	
4+00			5.02	100.80	97.03	
5+00			4.12	101.70	97.53	
6+00			3.73	102.90	98.03	
			5.80	100.02		Check on B.M. - OK

* Elev. is top of hub which is about 0.1' above the ground.

(Sheet 2 of 2)

Figure 14-23 Tile plan and layout

In some fine sandy soils there is insufficient colloidal material to hold the particles together, and there is danger of excessive movement of the sand particles into the drains. These soils require special precautions in drain construction. Open ditch subsurface drainage may be practical.

In peat and muck soils there is some tendency for the fine soil particles to enter the drain; there is danger of the tile in a tile drain shifting due to the unstable nature of the soil; and there is a tendency for newly drained muck and peat soils to settle considerably. For these reasons, it is recommended that drainage of these soils by buried drains be delayed until initial settlement has taken place. Mole drainage and open ditches may be used for initial drainage of this type of soil.

In porous soils, such as coarse sands and some peats, excessive lowering of the water table may cause a moisture deficiency during periods of drought. Being very porous, such soils have low capillary attraction and are unable to draw water up into the plant root zone of certain crops if the water table falls much below the root zone.

There are other soil conditions where drains are hazardous or impractical. In some soils, boulders or stones make drainage costs prohibitive. In other soils, the topsoil is satisfactory, but it is underlaid with unstable sand at the depth where drains should be installed, thus making installation more difficult or impossible. In other soils (as those containing glauconite, iron oxide or magnesium oxide), there is a tendency for the drain joints or perforations to seal over due to chemical action that takes place.

ECONOMIC FACTORS

Some soils can be drained satisfactorily, but the installation cost is so great the benefits derived do not justify the expense. In most instances, drain spacing of less than 50 feet for relief drainage cannot be justified unless high value crops or substantial indirect benefits are involved. Indirect benefits should be considered when, for example, the drying out of the land in orchards makes it possible for spray rigs to be used without bogging down.

Some soil can be drained satisfactorily but inherent productivity is so low that yields do not justify the expense. Suitable outlets may not be available and can be obtained only at prohibitive cost.

In some cases the financial ability of the farmer may not permit substantial indebtedness, even though returns from increased crop yields and reductions in the cost of production should pay for drain installation within a 5- to 10-year period.

USE OF LOCAL GUIDES

Drainage recommendations for the varied soil types, soil conditions, crops and economic factors can be made only in general terms. Investigational procedures, planning and methods of improving drainage conditions differ in many sections of the country. For these reasons local Technical Guides and State Drainage Guides should be consulted for recommendations and procedures for agricultural drainage.

2. TYPES OF SUBSURFACE DRAINAGE

RELIEF DRAINAGE

Relief drains are those installed approximately parallel to the flow of ground water to remove excess ground water percolating through the soil or to lower a high water table.

Relief drains will develop similar drawdown conditions on either side of the drain and the water table on either side will be the same at equal distances from the drain, provided the soil is homogeneous.

INTERCEPTION DRAINAGE

Interception drains are installed at approximately right angles to the flow of ground water to intercept subsurface flows. Interception drainage is applicable to broad, flat areas that are wet because of seepage from adjoining highlands. The proper location of drains for interception of seep planes is necessary to dry up wet areas caused by upland water. Seep planes are first located by soil borings or with posthole augers. The drain is then located so that continuous interception of such seep planes, adequate soil cover over the drain, and uniform grade to an available outlet are established. In steeply graded depressions or draws, a layout may consist of a main or submain drain located in the draw or to one side of the draw, with the interceptor lines located across the slope on grades slightly off contour.

DRAINAGE BY PUMPING

The objective of all subsurface drainage work is to remove excess water from the root zone of the crop. This is usually accomplished by installing relatively deep drains or open ditches. Water table levels may also be controlled by pumping from the ground water reservoir to maintain the desired water table level. In some irrigated areas where irrigation water is obtained from wells, the practices of irrigation and drainage may both be affected by the pumping of wells. This combination of practices is limited to areas with low salinity, where it is possible to maintain a proper salt balance. In salty areas, where pumping is used to effect drainage, the drain water is usually discharged into a natural outlet and not directly reused for irrigation. In some cases it is possible to mix the drain effluent with a water source of higher quality and thereby obtain water suitable for irrigation use.

The investigations necessary for planning pump drainage can be quite complex. Detailed information on the geologic conditions and the permeability of soil and subsoil materials is important. Design involves anticipating what the shape and configuration of the cone of depression will be after pumping. This, in turn, involves spacing of wells with respect to their areas of influence to obtain the desired drawdown over the area to be drained. Experience with this type of drainage indicates that it is costly and generally uneconomical. Consideration of this type drainage should be limited to high producing lands with a high net return per acre.

3. INVESTIGATIONS AND SURVEYS

TOPOGRAPHY

The amount of surveying needed to obtain topographic information depends on the lay of the land. Where land slopes are obvious, limited survey data are needed to locate drains. On flat or slightly undulating land, proper location of drains is not obvious and a topographic survey is necessary. Sufficient topographic information should be obtained for the complete job to be planned in advance of the installation. Insufficient data often results in a piecemeal system, which eventually is more costly to the owner. Methods for making topographic surveys and maps are covered in Chapter 1 of this manual.

SOILS

Unless sufficient soil borings were taken during the preliminary investigation, more should be taken as part of the design survey. The number of borings necessary will depend upon variations in the subsoil materials. Borings should be in sufficient number and depth to determine the extent of soil texture variations and to locate any lines of seepage, water movement, or water table elevations.

Permeability (hydraulic conductivity) of the soil should be determined at each change in soil layers when making the borings. Soil permeability may be determined by the auger hole or piezometer methods described in the National Engineering Handbook, Section 16.

Saline and alkali problems usually are associated with drainage in the western areas. Where salt crusts are visible or salinity is suspected, the soil should be sampled at various depths. A record of the species and condition of plant cover is important. A discussion of this problem is given in the National Engineering Handbook, Section 16.

GROUND WATER

Water table contour and depth to water table maps are very useful in planning subsurface drainage. The elevation of the water table at selected points, as obtained from borings, are plotted on a topographic map of the area. By interpolation, lines of equal water table are drawn. The result is a contour map of the water table. When a ground surface contour crosses a water table contour, the depth to the ground water is the difference in elevation of the two contours. Areas with a range of depths may be delineated on the map. Information such as direction of ground water flow and extent of high water table areas can be obtained from the map. For additional information on the preparation and use of the water table contour maps, refer to National Engineering Handbook, Section 16.

4. PLANNING AND DESIGN

THE OUTLET

Location of an Outlet

The starting point in planning a subsurface drainage system is the location of the outlet. Drains may discharge by gravity into natural or artificial ditches or main drains. Any of these are suitable provided they are deep enough and of sufficient capacity to carry the drainage water from their entire drainage system. Before proceeding with the design of the system, the adequacy of the outlet should be determined.

Capacity and Depth of Open Ditch Outlets

The outlet ditch must have the capacity to remove the drainage runoff from its watershed in a period of time sufficient to prevent crop damage. It must be deep enough so that when drains are installed at the specified depth there is at least one foot of clearance between the flow line of the drain and the normal low water stage in the ditch.

Capacity and Depth of Main Drains

When existing drains are used for the outlet, they should be in good condition and working properly. The main drain should have sufficient capacity to handle the proposed drainage system in addition to other systems it serves; and the depth should be sufficient to permit the new system to be installed at the depth specified.

Pump Outlet

Where a gravity outlet is not available, the possibilities of an outlet by pumping should be considered.

Vertical Drain Outlet

A vertical drain is a well, pipe, pit, or bore drilled into porous, underlying strata into which drainage water can be discharged. This is sometimes called a drainage well.

In many locations, it is common practice to drain sinkholes, field pockets and other lowland having no gravity outlet, into wells which penetrate into a water-absorbing stratum. These drains are classed as shallow and deep vertical drains.

Shallow vertical drains outlet into strata of coarse sand or gravel 20 feet or more below the surface. Performance of shallow drain is always uncertain as there is no assurance of a permanent outlet for the substrata. If there is no outlet the capacity of the drain will be limited to the water-holding capacity of the substrata.

Deep wells usually tap permanent sources of water for livestock and domestic use. Public health laws in some states regulate the use of wells for drainage and in many cases their use is prohibited. Vertical drainage usually is not recommended because of danger to public health. However, in some parts of the country it has proved the only satisfactory solution to drainage problems.

When a problem of using wells for a drainage outlet is involved, an engineer and a geologist should investigate the situation.

RELIEF DRAINAGE

Relief Drainage Systems

In order to plan a drainage system, a pattern must be selected which fits the topography, sources of detrimental water, and other field conditions. The following basic systems may be selected. (Refer to Figure 14-24.)

Random System

The random system is used where the topography is undulating or rolling and contains isolated wet areas. The main drain usually is placed in the lowest natural depression and smaller drains branch off to tap the wet areas. Often such drains become outlets for a more complete system established on the higher areas of the field. The depth, location, and capacity of random lines should be considered with this possibility in mind. The location of these drains usually is obvious from the topography.

Parallel System (Gridiron)

The parallel system consists of parallel laterals located perpendicular to the main drain. It is used on flat, regularly shaped fields and on uniform soil. Variations of this system are often used with other patterns. This system is frequently desirable because it provides intensive drainage of a given field or area. It is applicable also to land containing depressions or low areas which can be graded before installation of the system.

Herringbone System

The herringbone system consists of parallel laterals that enter the main drain at an angle, usually from both sides. This system can be used in place of the parallel system if the site conditions permit. It may also be used where the main is located on the major slope and the lateral grade is obtained by angling the laterals upslope. This pattern may be used with other patterns in laying out a composite system on small or irregular areas.

Drainage Coefficient

Humid Areas

Drains should have sufficient capacity to remove excess water from minor surface depressions and the major portion of the root zone of the soil profile within a period of 24 to 48 hours after rainfall ceases. The required amount of water to be removed is the drainage coefficient and, for subsurface drainage, is expressed as inches of water depth to be removed over a safe period of time, usually 24 hours, or as an inflow rate per unit of drain. Because of the differences in soil permeability, climate and crops, as well as the manner in which water may enter the drain, i.e., all from subsurface flow or part of it from subsurface flow and part of it from surface inlets, the coefficient must be modified to fit site conditions in accordance with local Drainage Guides or as described below:

1. Where drainage is uniform over an area through a systematic pattern of drains, and surface water is removed by field ditches or watercourses, the coefficient should be as shown in Table 14-4. Figure only the area to be drained as the drainage area.

Table 14-4 Drainage coefficients

Soil	Inches to be removed in 24 hours	
	Field crops inches	Truck crops inches
Mineral	3/8 - 1/2	1/2 - 3/4
Organic	1/2 - 3/4	3/4 - 1-1/2

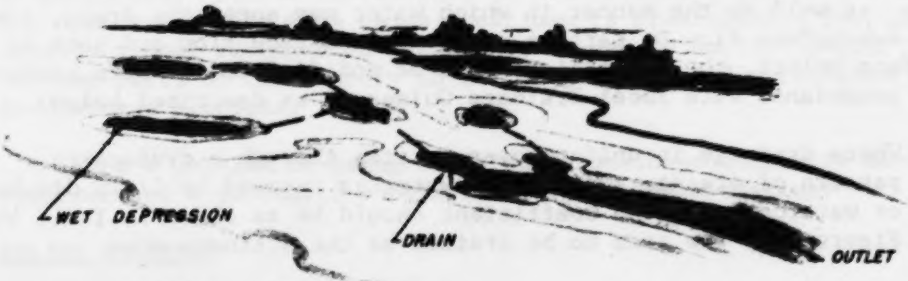
2. Where it is necessary to admit surface water through surface inlets to the drain, an adjustment in the required capacity of the drain must be made. Runoff from an area served by a surface water inlet takes place soon after the rainfall and enters the drain ahead of the ground water. In short lines or small systems where only 1 or 2 inlets are installed, the size of the drain may not need to be increased. As systems become larger or the inlets more numerous, an adjustment to the drainage coefficient should be made. The timing of the surface waterflow in relation to the entrance of ground water into the drain should be the basis for increasing the coefficient over those shown in Table 14-4.

3. A higher coefficient than those given in Table 14-4 may be necessary in some instances to hold crop damage to a minimum.

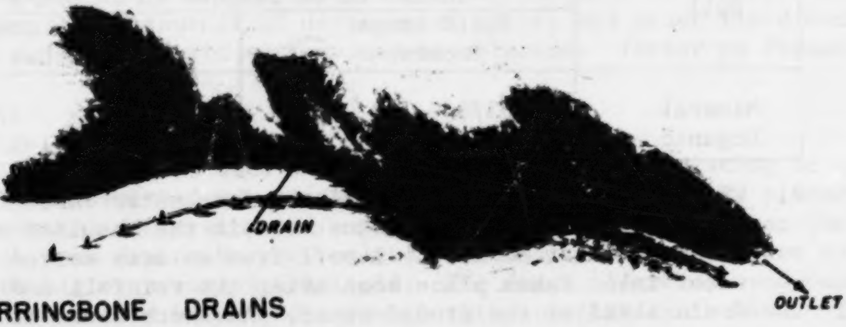
Drainage Coefficients for Western Irrigated Areas

In areas where rainfall is light, drainage coefficients applicable to local areas are variable and depend upon the quality and amount of irrigation water applied, methods of irrigation, crops to be grown and characteristics of the soil. Subsurface drains may yield from 0.10 to 40 cubic feet per second per mile.

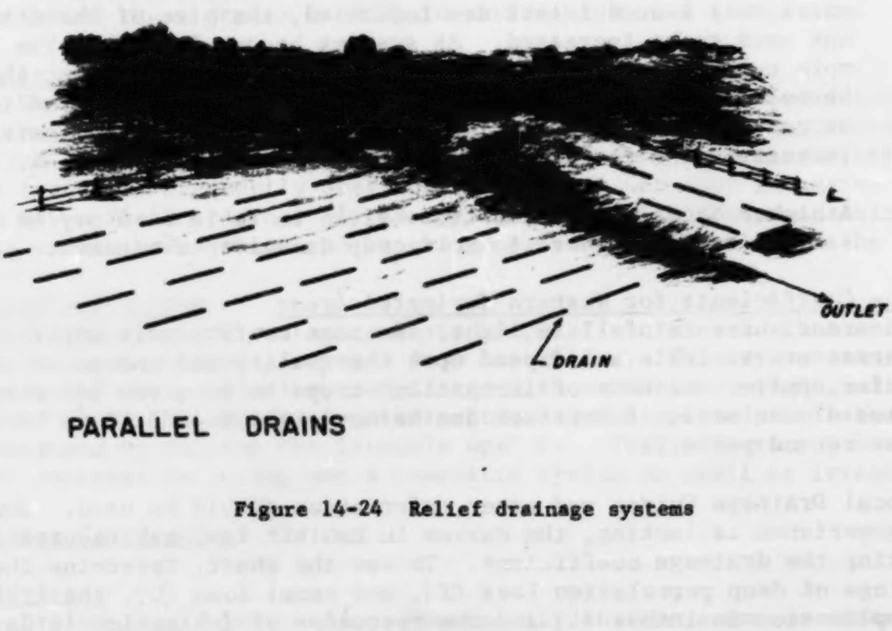
Local Drainage Guides and other information should be used. However, where experience is lacking, the curves in Exhibit 14-8 may be used for estimating the drainage coefficient. To use the chart, determine the total percentage of deep percolation loss (P), and canal loss (C), the irrigation application in inches (i) and the frequency of irrigation in days (F). The deep percolation loss includes the water which must be added to maintain a favorable salt balance in the soil and any losses to inefficient irrigation.


WET DEPRESSION
DRAIN
OUTLET

RANDOM DRAINS


DRAIN
OUTLET

HERRINGBONE DRAINS


OUTLET
DRAIN

PARALLEL DRAINS

Figure 14-24 Relief drainage systems

Example: Assume - Total loss (P+C) = 30 percent

Irrigation application (i) = 6 inches
Frequency of application (F) = 8 days

Find 30 on the left-hand vertical scale, follow horizontally from this point to intersect with line (i) = 6 inches. Translate this point vertically to intersect line (F) = 8. Follow horizontally from this point to the right-hand scale and read 0.0092 inch per hour as the drainage coefficient.

Depth and Spacing

Humid Area

The depth and spacing of drains are related in that generally the greater the depth of drain, the wider the spacing can be. There are other factors which enter into the determination of depth and spacing. Types of soil, climate, subsurface barriers, and crop requirements are important. In locations where there has been long experience with drain installations, the depth and spacing in various soils are well established.

Drains should be deep enough to provide protection against equipment loading and frost. Initial settlement in organic soils should be considered in depth selection. Main and submain drains must be deep enough to provide the specified depth for outlets of lateral drains. Also, the maximum depth at which drains can be laid in order to withstand trench loading varies with the width of trench and the crushing strength of the drain to be used. Allowable maximum depths are given under the heading of Materials.

In areas where drainage installations and knowledge of effective spacings are limited, the ellipse equation has been used to determine drain spacing. The ellipse equation may be expressed as follows:

$$S = \sqrt{\frac{4P\,(b^2 - a^2)}{Q_d}}$$

Where: (See Exhibit 14-9)

S = Spacing of drains (feet)

P = Coefficient of permeability (inches per hour)

b = Distance from the drawdown curve to barrier stratum at midpoint between the drains (feet)

a = Distance from the drains to the barrier (feet)

Q_d = Drainage coefficient (inches per hour)

NOTE: The units of P and Q_d may also be in "inches removal in 24 hours" or "gallons per square foot per day" but both must be in the same units in this formula. In using this formula for conditions where there is no known barrier present, it is assumed that a barrier is present at a depth equal to twice the drain depth.

Example:

1. Parallel drains are installed at a depth of 6 feet (d = 6).

2. Subsoil borings indicate an impervious barrier at 11 feet below the ground surface (a = 11 - 6 = 5).

3. Distance from ground surface to drawdown curve desired is 3 feet. Then (b = 11 - 3 = 8).

4. The average permeability (hydraulic conductivity) of subsurface materials is 1.2 inches per hour (p = 1.2).

5. The applicable drainage coefficient is 3/8 inch removed in 24 hours or 0.0156 inches per hour ($Q_d = 0.0156$).

Then:

$$S = \sqrt{\frac{4(1.2)(8^2 - 5^2)}{0.0156}} = 109.5 \text{ feet (use 110 feet)}$$

Charts for the graphical solution of the ellipse equation are shown in Exhibit 14-10, pages 1 and 2. Refer to the exhibit and solve the above example as follows:

Step 1. Refer to Exhibit 14-10, page 1. Find (a = 5) on the bottom scale. Project this point vertically to intersect the curve line (b = 8). From this point, follow horizontally to intersect radial line (P = 1.2). From this point, go vertically to intersect the top scale. Read the index number of (380).

Step 2. Referring to Exhibit 14-10, page 2, find index number (380) on the bottom scale. Project this point vertically to intersect the curve line ($Q_d = 0.0156$). From this point, follow horizontally to the right vertical scale and read the spacing of (S = 109 feet). (Use 110 feet.)

Western Irrigated Areas

Depth and spacing of drains are given in State Drainage Guides where experience has been extensive enough to do so. Where this information is not available, the ellipse equation, as previously discussed, is used to determine the spacing of relief drains.

Depth of drains in arid and semiarid irrigated areas usually is greater than in humid areas because of almost universal salinity of the ground water. Drains should have a minimum effective depth of 6 feet for medium textured soils and up to 7 feet for finer textured soils. This is necessary to maintain the ground water at depths of 4 to 5 feet midway between the drains. In most cases the depth of the laterals is dependent upon the outlet depth, slope of the ground surface, and the depth to any barrier which might exist.

The depth capacity of the drain-laying machine may limit the depth of the drain unless provisions are made for ramping part of the line. In ramping, a depressed roadway is excavated for the machine to obtain the needed depth in the deeper reaches of the drain line.

If the outlet for the drain is not deep enough to permit its installation to the required depth, then outletting into a sump with an automatic pump may be considered.

Size of Drains

The size of drains depends upon the required flow and the grade on which they are laid. The required flow is determined from the drainage coefficient and the area or length of drains contributing flow, plus any allowances for specially concentrated flow entering from the surface, springs, or other sources. The contributing drainage area for a complete drainage system should equal approximately the total length of all contributing lines multiplied by the spacing between such lines.

Random drains in poorly drained depressions are often used later as main drains for a more complete drainage system. It is advisable, where such expansion is likely, to include the additional area that such added drains would serve in determining the size of the initial random line. When surface water is admitted directly into a drain by surface inlets, the entire watershed contributing to the inlet should be included. Flow from such watersheds often can be reduced by use of diversion ditches.

Size of Main Drain

The size of clay or concrete draintile required can be determined directly from the Tile Drainage Chart, Exhibit 14-11, after grade, coefficient, and drainage area have been determined. The same chart may be used when the required flow and the grade of the drains are known. The size required for other types of drains should be determined by the use of appropriate roughness coefficients.

Example No. 1: (See Figure 14-25)

Given: Tract of land approximately 640 x 725 feet is to be drained for general crops. The drainage area is 10.65 acres. The drainage coefficient is 3/8 inch in 24 hours (0.0156 inch per hour). A parallel system with laterals spaced 66 feet apart requires 4 lines 660 feet long, 11 lines 370 feet long and 1 line 200 feet long, making a total of 6,910 feet of drain. The main, as shown from a plotted profile, is on a grade of .08 percent (.0008 per foot), and is to be clay draintile.

Required: Size of the main at the outlet and its capacity.

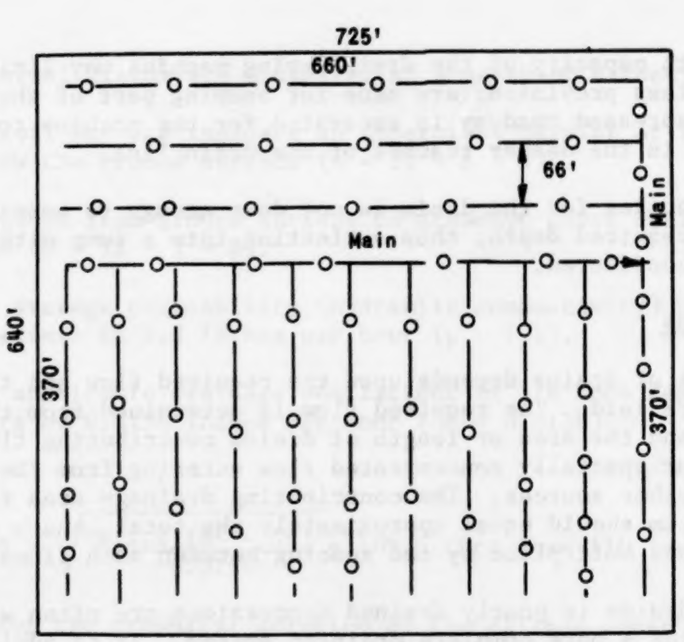


Figure 14-25 Subsurface drainage system

On Exhibit 14-11, find 10.65 acres in the 3/8-inch coefficient column of columns headed "Acres Drained" in the right-hand side. Trace this point horizontally to intersect the 0.08 vertical gradeline. The point of intersection lies between the lines for a 5-inch and 6-inch tile. Use the 6-inch tile. Continue the line to intersect the left-hand vertical scale and read 0.167 c.f.s. approximately. This is the discharge from the area. The top line of the space marked "6" represents the 6-inch tile flowing full when the hydraulic grade is the grade of the tile. From the intersection of the top line of "6" and grade of .08 percent, produce a line horizontally to intersect the left-hand vertical. The tile flowing full will discharge 0.180 c.f.s. which shows that the tile selected will not be flowing full.

Size of a Lateral

The size of a lateral may be found by first determining the required discharge for the lateral by use of the following formula or from Exhibit 14-12. When the discharge is determined, Exhibit 14-11 is used to determine the tile size.

In the case of parallel relief drains, the area served by the drain is equal to the spacing times the length of the drain plus one-half the spacing. The discharge can be expressed by the following formula:

$$Q_r = \frac{q\,S(L + S/2)}{43,200}$$

Where: Q_r = Relief drain discharge - c.f.s.

q = Drainage coefficient - in./hr.

S = Drain spacing - feet

L = Drain length - feet

Example:

Drain spacing - 200 feet (S)

Drain length - 3000 feet (L)

Drain coefficient - 0.04 in./hr. (q)

Tile grade - 0.30 percent

$$Q_r = \frac{0.04 \times 200(3000 + 100)}{43,200} = 0.575 \text{ c.f.s.}$$

Using Exhibit 14-12, find spacing of 200 feet on the left-hand vertical scale; follow horizontally to the right to intersect with the drainage coefficient curve 0.04. From this point follow vertically to intersect the length curve of 3,000 feet, then go horizontally to the right to read the discharge of 0.575 c.f.s. Turn to Exhibit 14-11, find the above discharge on the left-hand vertical scale and go horizontally to intersect the grade of 0.30 percent. An 8-inch tile will be required.

The tile chart has dashed velocity lines. In the above example, the velocity in the tile would be slightly over two feet per second.

In a drainage system, different sizes of drains may be needed. Required drain size may change at breaks in grade and changes in tributary area.

INTERCEPTION DRAINAGE

General

Interception drainage is used to intercept surface and subsurface water. The investigation, planning and construction of surface interception drains follow the requirements and procedures given under surface drainage. Interception of subsurface water is discussed in the National Engineering Handbook, Section 16.

Ground Water Movement

Information on ground water elevation and movement is necessary for proper establishment of interceptor drains. Some of the more common conditions indicating the need for interception drainage are illustrated in Figure 14-26, which is a sketch of a valley cross section extending beyond the ridge into the adjoining valley.

Most ground water for which drainage is required derives from recent rainfall that accumulates on or within the upper ground surface and, after replenishing the soil to water-holding capacity, moves downward through

ALLOW 8 PICAS TO TRIM

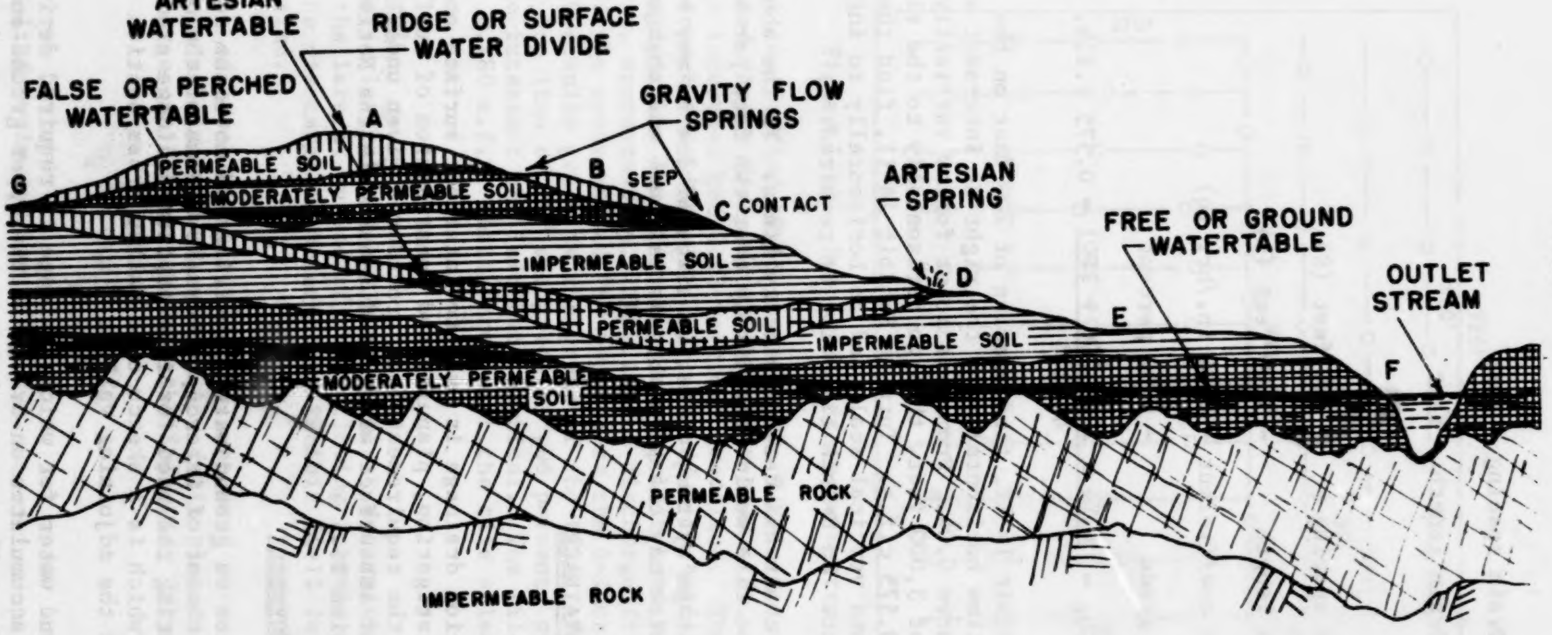

ARTESIAN WATERTABLE
RIDGE OR SURFACE WATER DIVIDE
FALSE OR PERCHED WATERTABLE
A
GRAVITY FLOW SPRINGS
G
PERMEABLE SOIL
MODERATELY PERMEABLE SOIL
B
SEEP
C CONTACT
ARTESIAN SPRING
D
IMPERMEABLE SOIL
PERMEABLE SOIL
IMPERMEABLE SOIL
FREE OR GROUND WATERTABLE
E
OUTLET STREAM
F
MODERATELY PERMEABLE SOIL
PERMEABLE ROCK
IMPERMEABLE ROCK

Figure 14-26 Ground water movement

the soil to the water table or a barrier above the water table. Here it accumulates and moves laterally, often parallel with the land slope, toward an outlet. Its movement may reach the surface and return to the subsurface a number of times in its course to an outlet. Barriers, within 8 to 20 inches of the surface, often cause perched water or false water tables above the true water table of a valley. A true water table seldom is encountered until well down the valley side slopes or on the valley floor. For example, rainfall penetrating a permeable surface soil below the ridge at "A" (Figure 14-26) may accumulate water over a less permeable subsoil during wet periods. Resistance to movement into the subsoil diverts most of the water over the less permeable layer to appear at the surface at location "B" as a wet weather seep. During the summer such seep spots may completely dry out. Also, where soil is shallow over less permeable layers, a false water table close to the surface may accumulate sufficient water to pond at the surface in wet seasons and later completely disappear.

The same water movement also can develop seeps at point "C." However, a larger collecting area and more complete interception by the impervious layer may accumulate sufficient water to produce a flowing spring, particularly if in a depression where the water converges and is confined in a small area. On the other hand, a rock ledge or compact layer may lay as a shelf with visible flow only at the depressions, even though this may be a small part of the total water coming to the surface along the same approximate contour.

Proceeding down into the valley trough, flow from adjoining watersheds can enter the problem. Springs developed from these sources frequently have year-round discharge. When flow is confined between impermeable layers, as at "D," it may build up a head of water a considerable distance above the point of issue and thus create an artesian supply that can discharge under pressure over an extended area. If not freely flowing, but covered by a mantle of moderately permeable to heavy soil, such springs may saturate an extensive area from great depths by pressure and capillary action, making their location and treatment difficult. Abrupt changes in grade of heavy soils, such as at "E", may slow water movement on the flatter slope enough to cause water accumulation and wetness at the surface.

On some sites, open wells or piezometers are necessary to locate the source and way in which subsurface flow takes place, particularly when it is coming to the surface from great depths.

Location of Drain

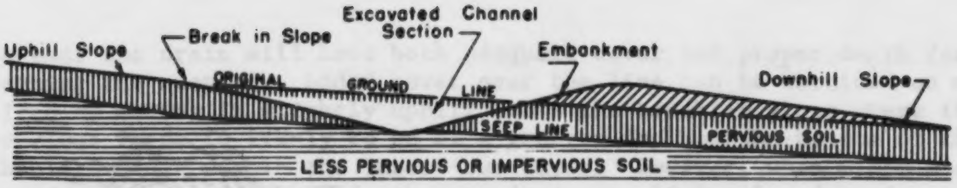
In the planning and establishment of interceptor drains for both surface and subsurface water, the location of the outlet is of first importance. Insofar as possible, cross drains should be laid out to utilize the best natural outlet available. Since the interceptor may intercept other drainageways and add their discharge to the selected outlet, it is necessary to check the adequacy of outlet to be used. Often, discharge can be spread over a well sodded pasture, stony field, or into gently sloping woods. In case a satisfactory natural outlet is unavailable, special channels may be constructed. Vegetative outlets on slopes are preferred over masonry or

similar channels for their cheap and ready establishment. They should be established well ahead of the interceptors so the turf will safely handle the concentrated flow. When such outlets must handle continuous flow, as supplied by springs, the center of the channel should be troughed to confine low flows. When surface wetness is undesirable, underground drainage can be provided by means of conduit placed along one side of the channel, well into the bank away from possible surface wash. Underground drains should be vented at breaks in grade to reduce suction at the head of the slope and pressure at the base. In flats at the base of slopes, main or lateral ditches of trapezoidal or parabolic section can be used.

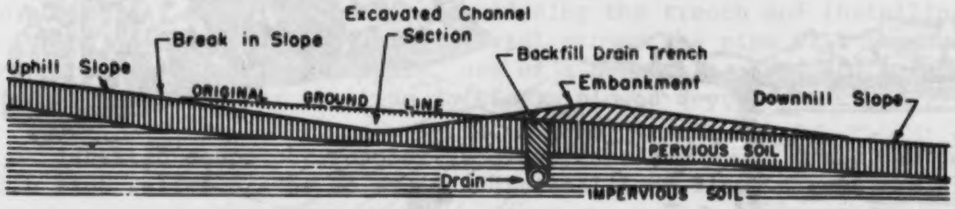
In planning and establishing an interceptor diversion, a few well placed lines at obvious seep planes and distinct changes in slope may be sufficient. In such cases, a detailed map may not be needed, and the line can be staked directly on the site. If subsurface interception must be considered also, the approximate location should be determined first from observations of surface conditions and preliminary borings. After the line is staked, additional borings should be taken along and across the staked line and the alignment shifted until good interception is obtained. In irregular bowl-shaped areas, some changes in grade or shifting of the diversion lines up or down slope may be necessary so that reasonably uniform farming strips, headlands, and access points for farming equipment can be obtained. If a uniform grade from one side to the other causes considerable divergence or location of the drain away from the approximate line of seepage and desirable pattern of farming strips, several parallel drains may need to be considered. When this is done, the least needed length of drain usually results from placing the shorter line at the higher elevation near the outlet. As an alternate, if an outlet is also available on the opposite side of the seep area, grade can be broken along a single line so that the fall is in both directions. The most advantageous point of breaking grade may require several trials until grade and alignment provide the desired location, interception, and outlet points. Such sites often have so many irregularities and outlet location problems that a complete contour map may be needed as an aid to planning.

Interception drainage may be accomplished by open ditches or subsurface drains. These are illustrated in Figure 14-27. The diversion on and across slopes is a direct development from erosion control practices. A channel used for surface water only (Figure 14-28) on sites having deep and heavy soils may be shallower than those required to intercept subsurface water movement. The open ditch must have sufficient depth to intercept subsurface water movement or be relocated so as to obtain depth. The ditches are frequently V-shaped with the bottoms and tops rounded out by construction and cultivation, so they nearly conform to hyperbolic sections and can be so designed. When wider ditches are necessary, they more nearly approach a parabolic section. Side slopes preferably should be 6:1 or flatter for ease of construction and farming. However, 4:1 or steeper side slopes may be necessary on land slopes greater than 12 percent.

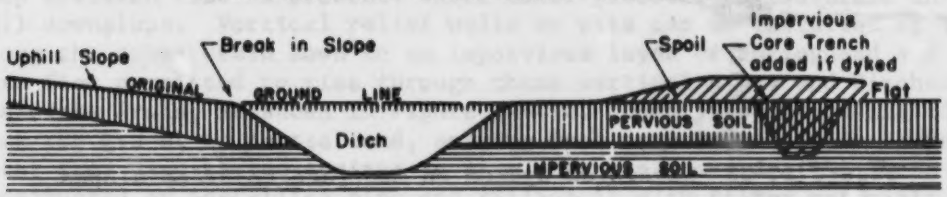
When a series of diversions is necessary to reduce the length of slope and contributing drainage area, spacing ordinarily should not exceed 200 feet for slowly permeable soils. More often, breaks in slope, location of


Excavated Channel Section
Break in Slope
Uphill Slope
Embankment
ORIGINAL GROUND LINE
Downhill Slope
SEEP LINE
PERVIOUS SOIL
LESS PERVIOUS OR IMPERVIOUS SOIL

A.- CROSS SECTION SHOWING DITCH AS SURFACE WATER DIVERSION AND SUB-SURFACE INTERCEPTOR ON SLOPE

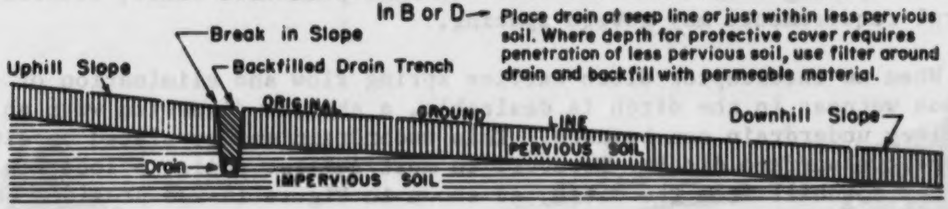

Excavated Channel Section
Break in Slope
Uphill Slope
Backfill Drain Trench
Embankment
ORIGINAL GROUND LINE
Downhill Slope
PERVIOUS SOIL
Drain
IMPERVIOUS SOIL

B.- CROSS SECTION SHOWING DITCH AS SURFACE WATER DIVERSION WITH DRAIN AS SUB-SURFACE INTERCEPTOR

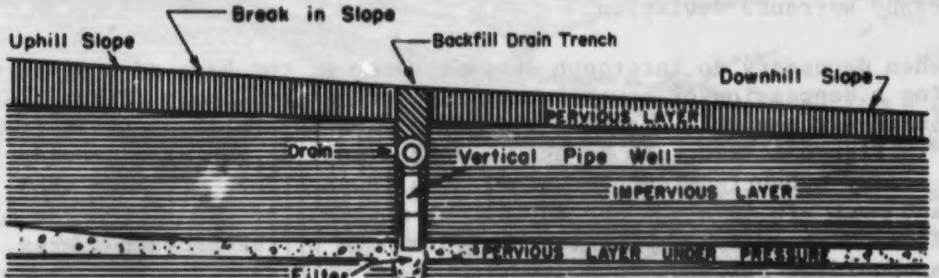

Impervious Core Trench added if dyked
Break in Slope
Spoil
Uphill Slope
ORIGINAL GROUND LINE
Flat
Ditch
PERVIOUS SOIL
IMPERVIOUS SOIL

C.-CROSS SECTION SHOWING DITCH AS SURFACE WATER DIVERSION AND SUB-SURFACE INTERCEPTOR FOR FLAT LAND

In B or D— Place drain at seep line or just within less pervious soil. Where depth for protective cover requires penetration of less pervious soil, use filter around drain and backfill with permeable material.


Break in Slope
Uphill Slope
Backfilled Drain Trench
ORIGINAL GROUND LINE
Downhill Slope
PERVIOUS SOIL
Drain
IMPERVIOUS SOIL

D.-CROSS SECTION SHOWING DRAIN AS SUB-SURFACE INTERCEPTOR


Break in Slope
Uphill Slope
Backfill Drain Trench
Downhill Slope
PERVIOUS LAYER
Drain
Vertical Pipe Well
IMPERVIOUS LAYER
PERVIOUS LAYER UNDER PRESSURE
Filter

Place additional vertical pipe wells as needed to one side of drain and join with filter material used as backfill.

E.-CROSS SECTION SHOWING RELIEF WELL AND INTERCEPTOR DRAIN

Figure 14-27 Typical interceptor installations

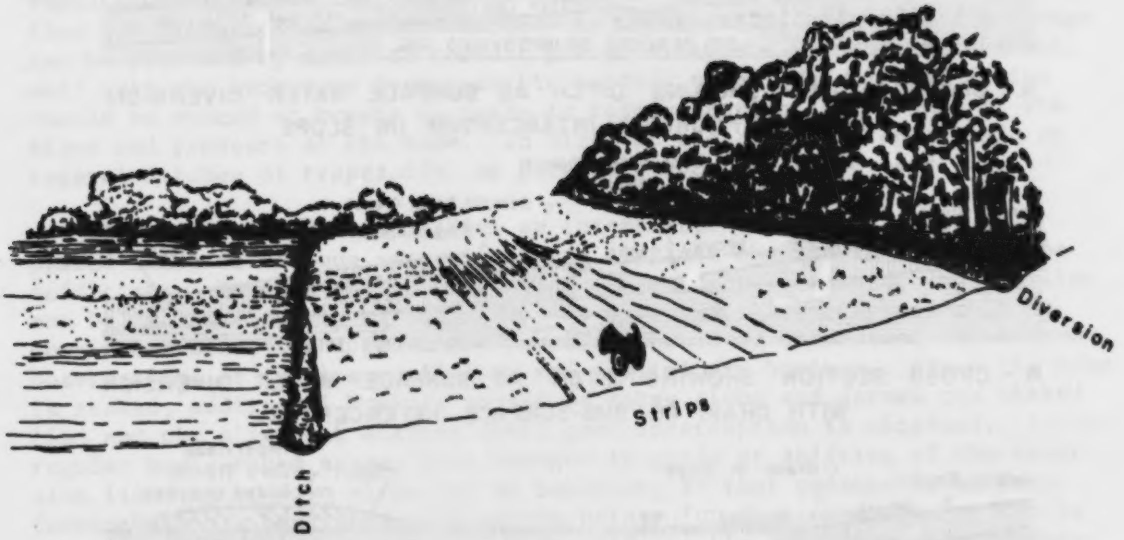


Figure 14-28 Diversion system on moderate to steep slopes

spring or seep lines, and the necessary location of the top diversion results in spacing less than 200 feet. In more permeable soils, erosion control requirements may govern spacing.

When an interceptor ditch carries spring flow and elimination of continuous wetness in the ditch is desirable, a shallow diversion with an auxiliary underdrain can be used. This underdrain may be placed on either side of the surface ditch. However, in most shallow soils, a location slightly downhill from the ditch, as shown in Figure 14-27B provides deeper interception and added cover from the embankment. The subsurface drain need not follow the course of the surface ditch throughout its length if topography warrants deviation.

When necessary to intercept surface water at the base of a slope surrounding a depression or at the outer edge of a flood plain (Figure 14-29), a drainage ditch with a standard trapezoidal or parabolic cross section, as shown in Figure 14-27C, can be used. Depths must be ample to provide for: 1) Necessary subsurface interception; 2) allowance for shrinkage when peat and muck are involved and 3) lateral movement of water when the ditch is used also as an outlet for internal drainage of the protected area. Spoil always should be placed on the downslope bank in order to permit free movement of upland water into the ditch. Spoil also may be used in diking to gain added channel capacity for overflow protection. If diking is not needed, spoil should be spread to facilitate maintenance.

When drainage areas are only a few acres in extent, subsurface drainage often can be used alone for interception of seeps and springs, as illustrated in Figure 14-27D. Such lines usually are located close to breaks in grades so that the drain will have both adequate cover and proper depth for intercepting the seepage. Added cover over the line can be obtained on many sites by moving it slightly uphill above the break in slope where the impervious layer is likely to be at a greater depth. The bottom of the drain should be just within the impervious layer. However, when minimum cover is not available at this depth, the drain should be placed as far into the impervious layer as necessary to attain the needed cover even though this may reduce the amount of flow into the pipe and its potential capacity. To counteract this, deepening and widening the trench and installing 4 to 6 inches of envelope or filter material around the pipe will improve flow into the drain. In heavy soils, use of a permeable material is desirable also as backfill over the line to within plowed depth.

Isolated seeps outcropping at elevations above the drain can be tapped with stub relief drains to avoid additional long lines across the slope.

When pervious layers are considerably below normal drain depth, or deep artesian flow is present, water under pressure may saturate an area well downslope. Vertical relief wells or pits can be installed at intervals along the cross drain down to an impervious layer or springhead and the excess flow permitted to rise through these vertical pipes and discharge into the cross drain, as shown in Figure 14-27E. Open pits may be filled with bank run gravel or coarse sand, serving much as a French drain to permit water from deep-seated springs to rise into the cross drain. These can be constructed by installing pipe and filling it with filter material; after which the pipe can be withdrawn, leaving an unlined permeable channel.

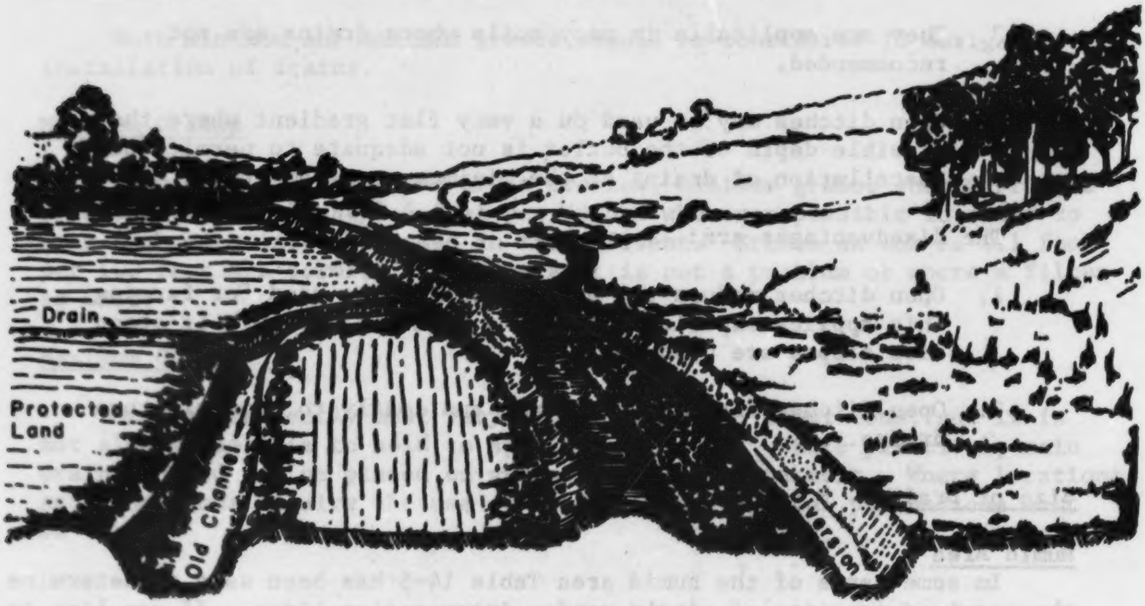


Figure 14-29 Diversion system on bottom land

Use of Ditches or Drains

Ditches may be used to lower the water table where drains are not feasible. They are used in shallow hardpan soils where the depth of the soil does not permit installation of tile. They are used in deep soils, either as a temporary measure or permanent installation, when fields are cultivated in lands such as for sugarcane. The entrance of surface water presents problems in preventing bank erosion.

Ditches may be used as temporary installations to intercept and measure subsurface flow. Often a ditch is retained as a permanent installation if the flow is so great that a drain installation would be too costly.

Ditches must be deep enough to tap and provide an outlet for ground water found in shallow, permeable strata or in water-bearing sands. The spacing of the ditches varies with soil permeability and crop requirements. The capacity of the ditches usually is greater than required due to the required depth and construction equipment used. Refer to National Engineering Handbook, Chapter 16, for additional information and to the State Technical Guides for recommendations.

The following are some advantages and disadvantages in the use of open ditches:

The advantages are:

1. Open ditches nearly always have a smaller first cost than drains.
2. Inspection of open ditches is more easily accomplished.
3. They are applicable in many soils where drains are not recommended.
4. Open ditches may be used on a very flat gradient where the permissible depth of the outlet is not adequate to permit the installation of drains at the minimum required grade.

The disadvantages are:

1. Open ditches reduce the area of land to be used for farming. This applies especially to soils that are unstable if steep side slopes are used.
2. Open ditches are more difficult and costly to maintain than drains.

Size of Drains

Humid Area

In some parts of the humid area Table 14-5 has been used to determine the required capacity of single random intercepting lines. If one line is insufficient, additional lines are added.

Table 14-5 Interception tile inflow rates

Soil Texture	Inflow Rate per 1,000 Feet of Line in c.f.s. 1/ 2/
Coarse sand and gravel	0.15 to 1.00
Sandy loam	0.07 to 0.25
Silt loam	0.04 to 0.10
Clay and clay loam	0.02 to 0.20

1/ Discharge of flowing springs or direct entry of surface flow through a surface inlet or filter must be added. Such flow should be measured or estimated.

2/ Required inflow rates for interceptor lines on sloping land should be increased by 10 percent for slopes 2 to 5 percent, by 20 percent for 5 to 12 percent and 30 percent for slopes over 12 percent.

Western Irrigated Areas

Darcy's Law relating to the flow of gravitational water through soils has been used to approximate the discharge. Measuring discharge of an open pilot interceptor has been employed. Local experience with interception drainage is usually relied upon. Additional information can be found in the National Engineering Handbook, Section 16, and State Drainage Guides. The procedure for obtaining the drain size after the discharge has been determined has been discussed earlier.

GRADES AND VELOCITIES

Both minimum and maximum grades should be considered in design and installation of drains.

Minimum Grades

When silt and fine sand are a problem, minimum grades should produce a velocity of at least 1.4 feet per second whenever possible in order to keep such materials suspended in the effluent. Grades as low as 0.1 foot per 100 feet are permissible where silt is not a problem or where a filter is used.

Maximum Grades

Grades frequently must vary with topographic conditions, and it is not always possible to hold to specific maximums. Where practical, main drains should not be placed on grades much over 2 percent. Where locations and conditions require the use of steep grades, special precautions must be taken.

Some of the added precautions which should be considered when drains are to be installed on steep grades are:

1. Use drains of uniform size and shape, and with smooth ends or joints.

2. Lay the drain in a firm foundation with tight-fitting joints and blind with the heaviest material available.

3. Use a glass-fiber filter, plastic guards, or other material to wrap the joints to prevent soil from entering the drain.

4. Use bell-and-spigot or tongue-and-groove pipe with sealed or unsealed joints for protection against high velocities.

5. The use of drains longer than 12 inches is recommended to reduce the number of joints.

The need for a breather pipe near the beginning of a steep section and a relief well at the point where a steep section changes to a flat section should be considered. This will be determined by the velocities in the drain, the soil in which the drain is laid, and the capacity of the drain below the steep section with respect to that in the steep section.

5. MATERIALS

GENERAL

Drain materials commonly used are clay, concrete, bituminous fiber, asbestos cement, plastic, and metal. Refer to current State Standards and Specifications for specifications for the material being used.

Allowable Depths

The maximum depth at which drains can be laid with safety varies with the crushing strength of the drain, type of bedding or foundation on which the drain will be laid, the width of the trench and the weight of the backfill.

The crushing strength of the drain material to be installed is listed in the pertinent specifications.

The type of bedding depends upon construction methods. When a drain is installed by backhoe or dragline and the bottom of the trench is not shaped to conform to the drain, or special care is not exercised to fill all the spaces under and around the tile with granular material, the drain will only support a loading equal to the crushing load given in the specifications. If a factor of safety is desired, the load should be decreased.

When installation of drains is made by trenchers, the tile is laid in a shaped foundation made by the shoe of the machine. Placing of granular material of topsoil or gravel around the drain will approach a bedding condition called ordinary, which will permit a load of approximately 1.5 times the crushing load given in the specifications. This allows the drain to be installed in a deeper or wider trench than if no attention had been paid to the bedding of the drain.

Ordinary bedding is that method of bedding a ditch conduit where the trench is shaped to fit the lower part of the conduit exterior reasonably close for a width of about 50 percent of the conduit diameter. The remainder of the conduit is covered to a height of at least 0.5 foot above its top with granular materials that are shovel-placed and shovel-tamped to completely fill all spaces under and around the drain. The present method of installing drains with trenching machines is so well done that for all practical purposes ordinary bedding may be assumed.

The above refers to rigid type drains. Flexible conduits, properly installed, will withstand greater trench depths than rigid type drains. Therefore, the same depths and widths of the trench can be applied to both with safety. Table 14-6 shows the allowable trench depth in feet for drains with different widths of trench.

Table 14-6 Maximum allowable trench depth in feet for drains with varying widths of trench based on ordinary bedding 1/

Tile Size in.	Crushing Strength lbs/lin.ft	Width of Trench - Inches								
		14	16	18	20	22	24	26	28	30
4	800 1100	*Inf. "	13.5 Inf.	10.5 Inf.	10.5 12.5	10.5 12.5	10.5 12.5	10.5 12.5	10.5 12.5	10.5 12.5
5	800 1100	" "	16.5 Inf.	8.5 Inf.	7.5 12.0	7.5 9.5	7.5 9.5	7.5 9.5	7.5 9.5	7.5 9.5
6	800 1100	" "	" "	8.5 Inf.	6.5 12.5	6.5 8.5	6.5 8.5	6.5 8.5	6.5 8.5	6.5 8.5
8	800 1100	" "	" "	9.0 Inf.	7.0 12.5	6.0 9.0	5.5 7.5	5.5 7.0	5.5 7.0	5.5 7.0
10	800 1100	" "	" "	9.0 Inf.	7.0 12.5	6.0 9.0	5.5 7.5	5.0 6.5	5.0 6.0	5.0 6.0
12	800 1100	" "	" "	9.5 Inf.	7.5 13.0	6.0 9.0	5.5 7.5	5.0 7.0	4.5 6.0	4.5 5.5
15	870 1100				8.5 13.0	7.0 9.5	6.5 8.0	6.0 7.0	5.0 6.5	5.0 6.0
18	930 1200						7.0 9.5	6.5 8.5	6.0 7.5	5.5 7.0

* Inf. = infinity

1/ Reference: Based on Marston's formula.
Soil - 120# w/ft.

ENVELOPES AND FILTERS

Sand and Gravel Envelopes

The basic functions of an envelope are to provide a bedding for the drain and to improve the permeability in the zone around the drain. The main requirement of the material in the envelope is that it have a permeability higher than the base material. The maximum size of the envelope material should not be greater than 1½ inches, and not more than 10 percent of the material should pass the No. 60 sieve. The gradation of the material is not important as it does not serve as a filter. The thickness of the envelope should be at least 3 inches.

Filters

Filters for drains are used to facilitate passage of water to the drain and to prevent movement of fine particles of silt and sand into the drain. Blinding material such as topsoil, straw, salt hay, sawdust and wood chips, or loose coverings of tar paper over the joint have provided effective filtering action in some soils for long periods of time. Fiber glass filter wrappings also are effective. However, the most suitable material is the sand-gravel filter. In addition to its filtering action, sand-gravel filter material provides excellent bed material for cushioning tile and pipe when laid in the stony soils frequently encountered. A good filter should be well graded from coarse to fine and within a limited size range of particles. Good concrete sand, as specified by the American Association of State Highway Officials, has been found to meet the requirements of an adequate filter for most soil conditions encountered. This material is essentially a mixture of medium and coarse sand with fine and medium gravel, in which the particles are well graded from a minimum size of about 1/2 millimeter (grains held on a No. 30 sieve) to a maximum of about 3/8 inch. Clean bank-run gravel, suitable for use in mixing concrete, usually is available locally but should be checked for adequacy. Since filter material is rather fine, clay or concrete draintile must be butted against each other. For design of a filter see National Engineering Handbook, Section 16, or the local Technical Guide.

Filter material, other than the manufactured types, should completely encase the pipe with a thickness of at least 3 inches. The trench in which the drain is to be placed should be excavated below grade a depth equal to the thickness of filter and the trench then filled to grade with the filter material before laying the pipe. After the pipe is laid, the trench should be filled with filter material to the required depth. Filter and envelope depths may range from a 3-inch cover over the drain to within 1 foot of the ground surface when interception through heavy soil is desired and found practical.

Determination of Need of Envelopes or Filters

The purpose of these have been mentioned above as being related to the soil types. Table 14-7 is a guide to relate the needs to the Unified Soil Classification System. It will be noted that envelopes are optional in all cases where filters are not used. The need for envelopes should be based primarily on soil permeability and requirements for bedding.

Table 14-7 A classification to determine the need for drain filters, envelopes, and minimum flow velocities

Unified Soil Classification	Soil Description	Filter Recommendation	Envelope Recommendation	Recommendations for Minimum Drain Velocity
SP (fine) SM (fine) ML MH	Poorly graded sands, gravelly sands Silty sands, poorly graded sand-silt mixtures. Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity. Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Filter needed	Not needed where sand and gravel filter is used but may be needed with flexible drain and other type filters.	None
GP SC GM SM (coarse)	Poorly graded gravels, gravel-sand mixtures, little or no fines. Clayey sands, poorly graded sand-clay mixtures. Silty gravels, poorly graded gravel sand silt mixtures. Silty sands, poorly graded sand-silt mixtures.	Subject to local onsite determination	Not needed where sand and gravel filter is used but may be needed with flexible drain and other type filters.	With filter - none Without filter - 1.40 feet/second
GC CL SP, GP (coarse) GW SW CH OL OH Pt	Clayey gravels, poorly graded gravel-sand-clay mixtures. Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. Same as SP & GP above Well graded gravels, gravel-sand mixtures, little or no fines. Well graded sands, gravelly sands, little or no fines. Inorganic, fat clays. Organic silts and organic silt-clays of low plasticity. Organic clays of medium to high plasticity. Peat	None	Optional May be needed with flexible drain.	None - for soils with little or no fines. 1.40 feet/second for soils with appreciable fines.

6. APPURTENANCES

SURFACE INLETS

Surface inlets should be used in low areas where surface drainage otherwise cannot be provided (Figure 14-30). These must be properly constructed to prevent washouts and silting of the line. Surface inlets should be avoided wherever possible. If silt is a hazard, place a silt trap (Figure 14-31) at a convenient location immediately downstream from the inlet or use a blind inlet (Figure 14-32).

JUNCTION BOXES

Junction boxes should be used when two or more main or submain drains join or when several laterals join at different elevations. If the junction is in a cultivated field, the box should be constructed so that the top is at least 18 inches below the surface of the ground. It can be capped and covered and its position referenced for future relocation. (See Figure 14-31.)

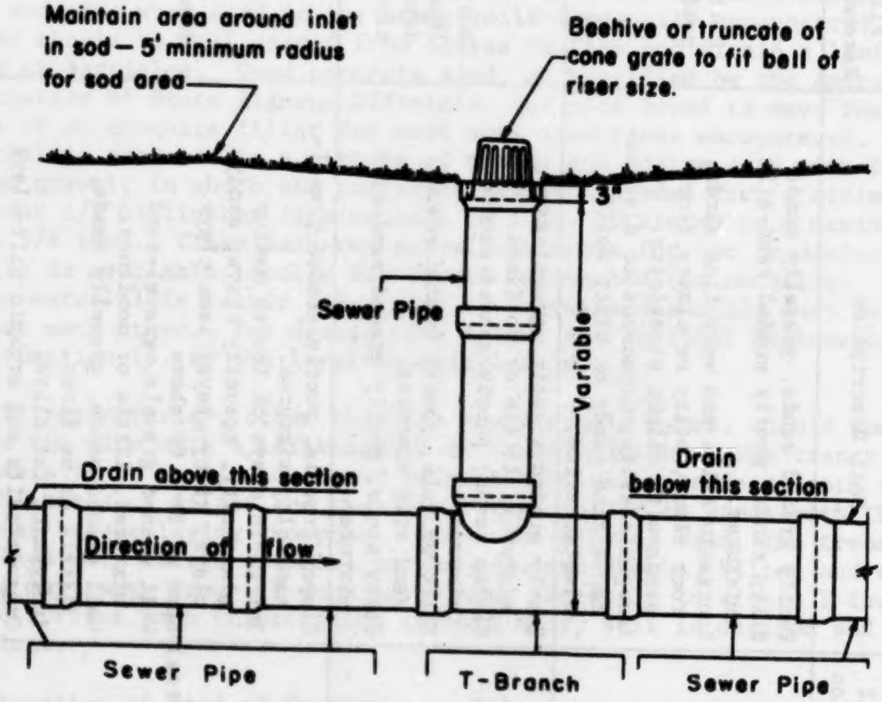

Maintain area around inlet in sod — 5' minimum radius for sod area
Beehive or truncate of cone grate to fit bell of riser size.
3"
Sewer Pipe
Variable
Drain above this section
Drain below this section
Direction of flow
Sewer Pipe
T-Branch
Sewer Pipe

Figure 14-30 Surface inlet

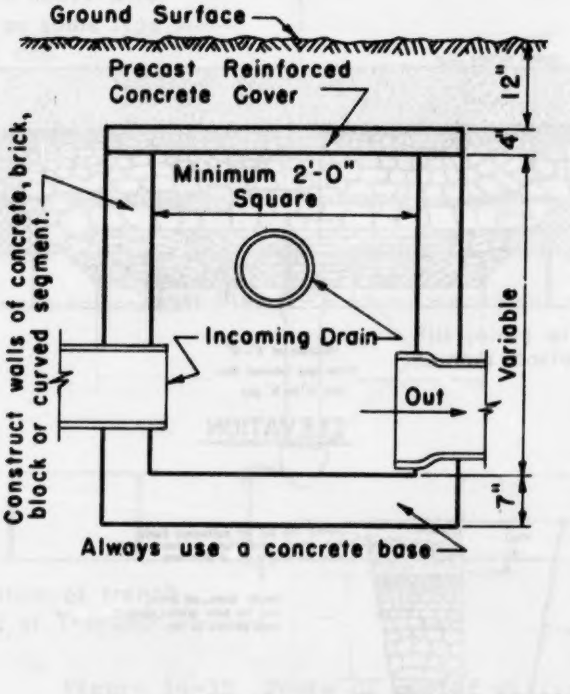
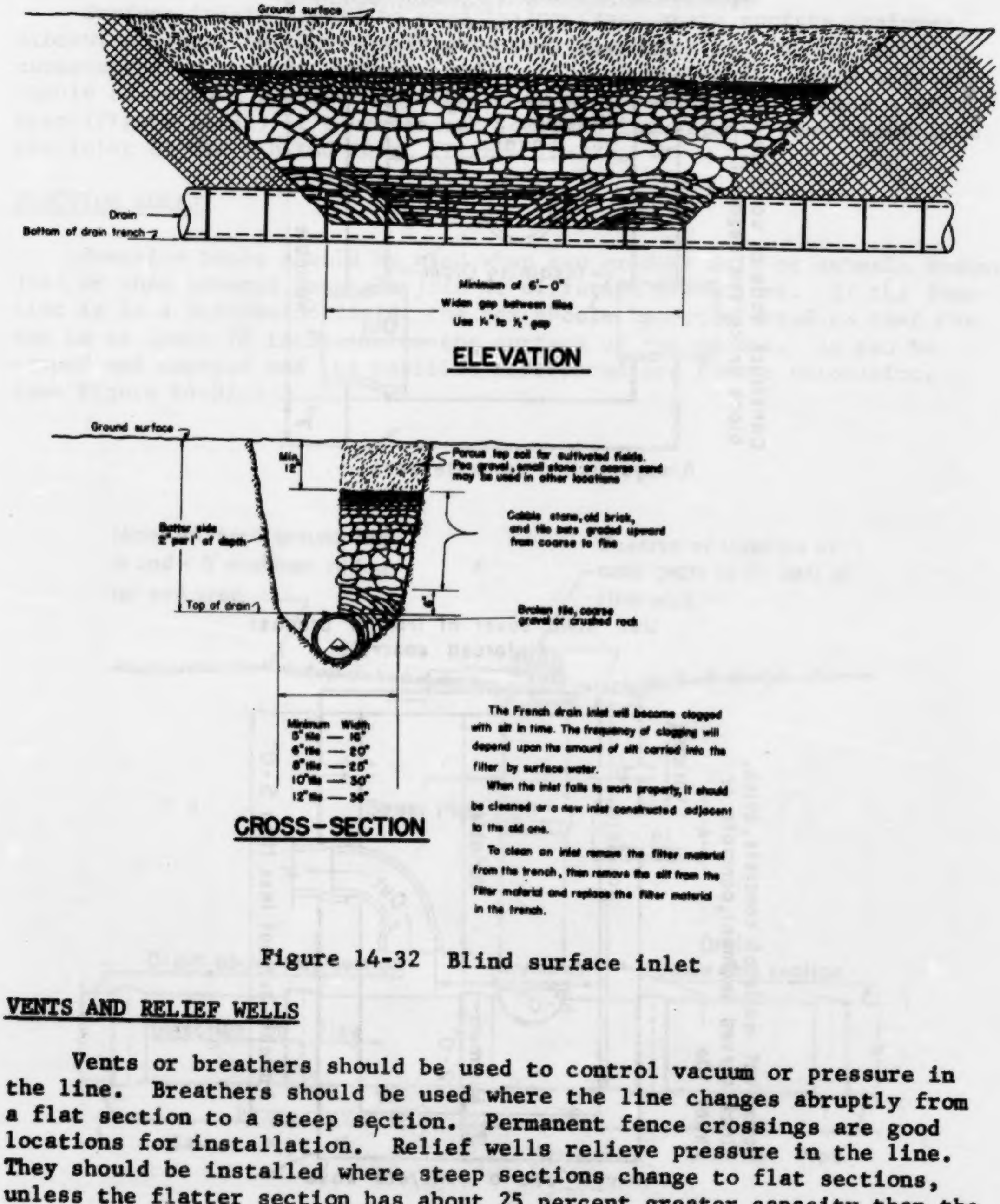

Ground Surface
Precast Reinforced Concrete Cover
12"
4"
Minimum 2'-0" Square
Construct walls of concrete, brick, block or curved segment.
Incoming Drain
Out
Variable
7"
Always use a concrete base
Use solid cover of iron or precast reinforced concrete
Variable
In
Variable
Out
Minimum- 2'-0"
Minimum- 2'-0"
7"
Variable but not less than 5'-0"
Construct walls of concrete, brick, block, curved segment, concrete or sewer tile.
Always use a concrete base

Figure 14-31 Junction box, catch basin, and silt trap


Ground surface
Drain
Bottom of drain trench
Minimum of 6'-0"
Widen gap between tiles
Use ¼" to ½" gap
Ground surface
Min. 12"
Porous top soil for cultivated fields. Pea gravel, small stone or coarse sand may be used in other locations
Batter side 2" per 1' of depth
Cobble stone, old brick, and tile bats graded upward from coarse to fine
6"
Top of drain
Broken tile, coarse gravel or crushed rock
Minimum Width
5" tile — 16"
6" tile — 20"
8" tile — 25"
10" tile — 30"
12" tile — 36"

ELEVATION

CROSS-SECTION

The French drain inlet will become clogged with silt in time. The frequency of clogging will depend upon the amount of silt carried into the filter by surface water.

When the inlet fails to work properly, it should be cleaned or a new inlet constructed adjacent to the old one.

To clean an inlet remove the filter material from the trench, then remove the silt from the filter material and replace the filter material in the trench.

Figure 14-32 Blind surface inlet

VENTS AND RELIEF WELLS

Vents or breathers should be used to control vacuum or pressure in the line. Breathers should be used where the line changes abruptly from a flat section to a steep section. Permanent fence crossings are good locations for installation. Relief wells relieve pressure in the line. They should be installed where steep sections change to flat sections, unless the flatter section has about 25 percent greater capacity than the steeper section. They should also be used on lines with surface inlets, particularly when such inlets are large. (See Figure 14-33.)

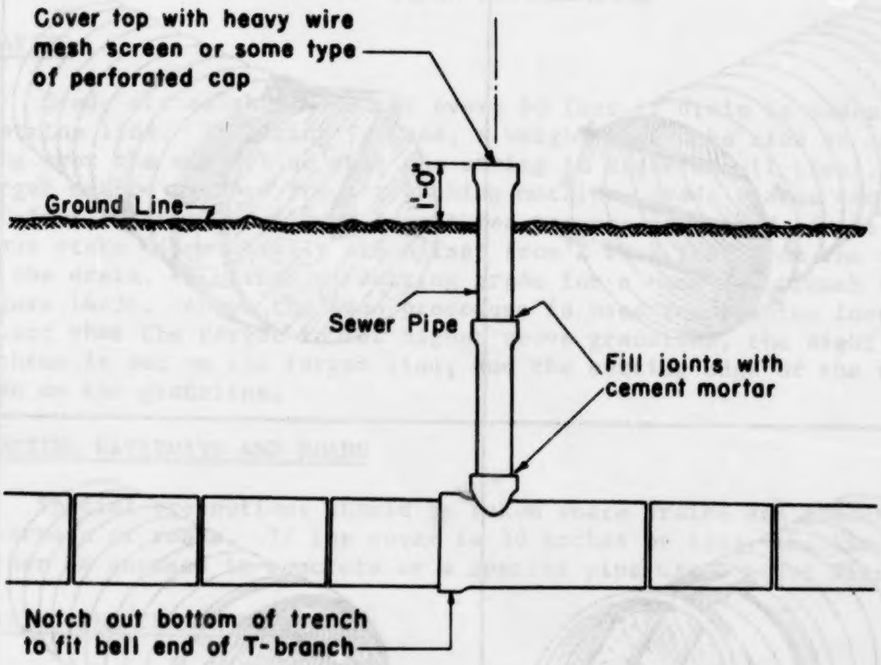

Cover top with heavy wire mesh screen or some type of perforated cap
1'-0"
Ground Line
Sewer Pipe
Fill joints with cement mortar
Notch out bottom of trench to fit bell end of T-branch

Figure 14-33 Vents of relief wells

OUTLET PROTECTION

Where drains outlet into an open ditch, the end of the line should be protected. If surface water enters the outlet at the same location as the drain, some type of structures is necessary. Where there is no surface water, the most practical and economical outlet is a section of rigid pipe, metal preferred, which should conform to requirements shown in Figure 14-34. A swing gate or some type of grating or coarse screen should be used on all outlets to exclude rodents and other small animals. (See Figure 14-35.) Screens should have mesh sizes of not less than one inch. When surface water enters a system directly, swing gates, rather than fixed screens or grates should be used.

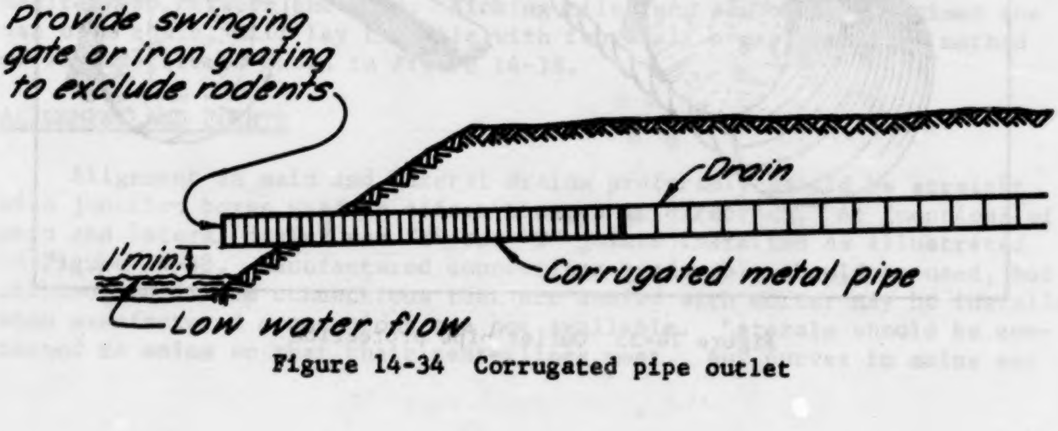

Provide swinging gate or iron grating to exclude rodents
Drain
1'min.
Corrugated metal pipe
Low water flow

Figure 14-34 Corrugated pipe outlet

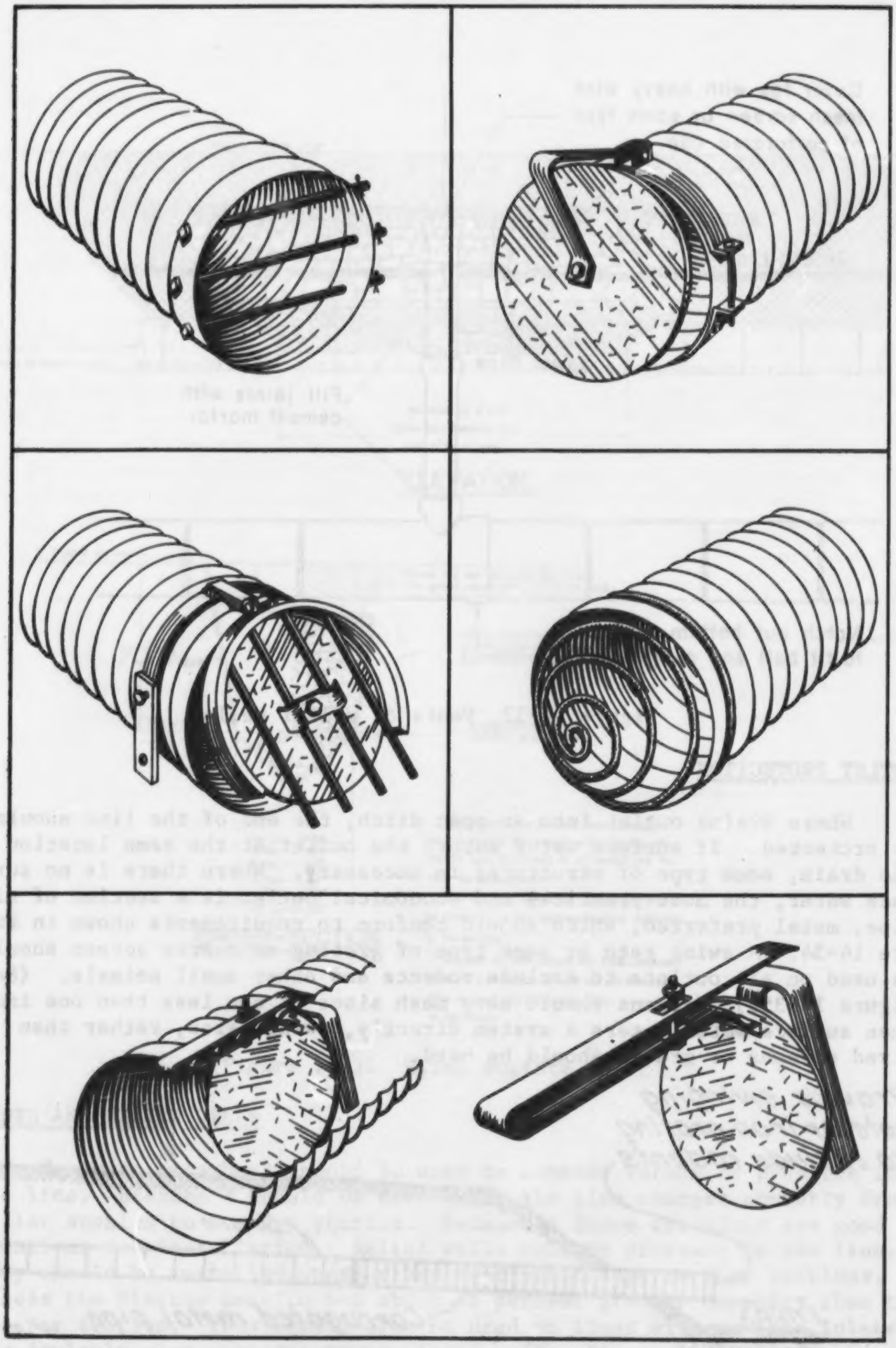


Figure 14-35 Outlet pipe protection

7. DRAIN INSTALLATION

STAKING

Grade stakes should be set every 50 feet if drain is installed from a string line. If string is used, a weight should be tied at each end and hung over the support so that the string is tight at all times. If the target method is used for a trenching machine, grade stakes can be set at 100-foot intervals. Always have three targets set ahead of the machine. Grade stake lines usually are offset from 2 to 4 feet from the centerline of the drain. A method of setting grade for a hand dug trench is shown in Figure 14-36. About the same procedure is used for machine installation, except that the target is set higher above gradeline, the sight of the machine is set on the target line, and the cutting edge of the wheel is then on the gradeline.

CROSSING WATERWAYS AND ROADS

Special precautions should be taken where drains are placed under waterways or roads. If the cover is 30 inches or less, the line should either be encased in concrete or a special pipe used. (See Figure 14-37.)

SHAPING THE TRENCH BOTTOM

In hand trenching, the bottom of the drain trench should be shaped with a drain scoop, so that about one-fourth of the circumference of the drain is on solid ground. Trenching machines shape the trench properly as a part of the trenching operation. Where drains are laid through unstable pockets of soil, one of the following materials for supporting the drain should be placed in the bottom of the trench before laying it: stable soil, coarse hay, straw, tough sod, crushed limestone, or gravel filter. Where none of these is feasible or adequate, cradle the drain. Where cradling is used, the rail-and-cleat method should be used, as shown in Figure 14-36.

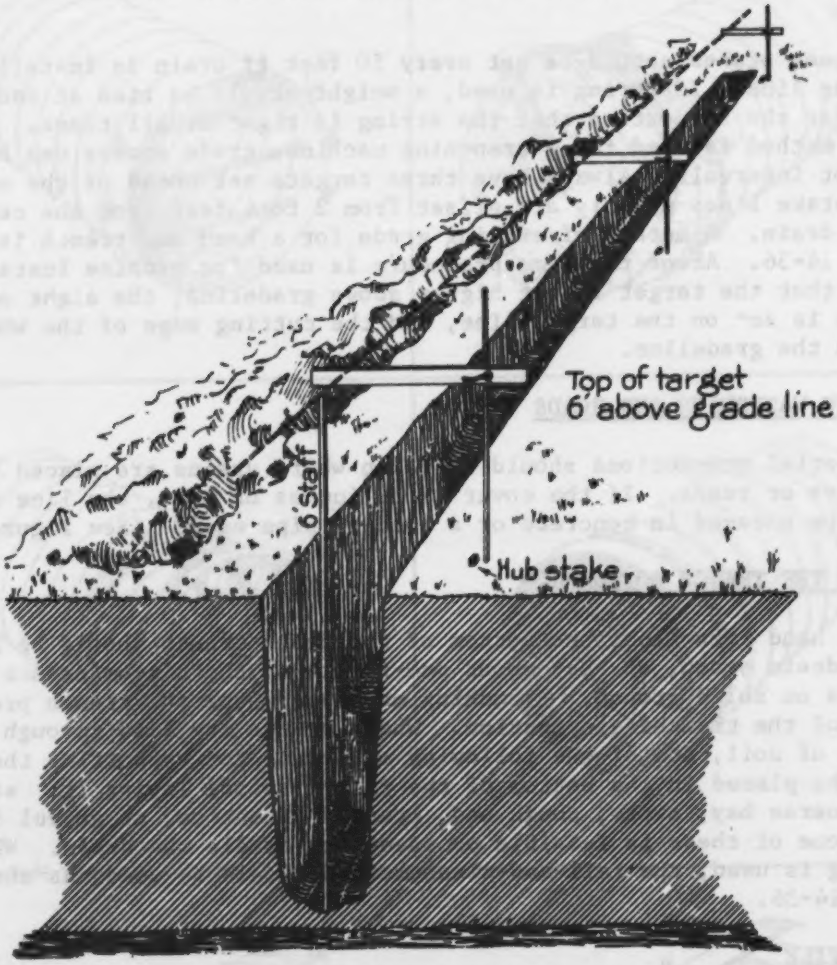
LAYING TILE

Tile is placed in the trench by hand, tile hook, or by chute provided on the trencher. Constant attention should be given to obtain the desired gap between the tile. Kicking tile into place, or sometimes the use of a chute, will lay the tile with too small a gap. Correct method of laying tile is shown in Figure 14-38.

ALIGNMENT AND JOINTS

Alignment in main and lateral drains preferably should be straight with junction boxes used to effect changes in direction. At junctions of main and lateral drains use "Y" and "T" joints installed as illustrated in Figure 14-38. Manufactured connections preferably should be used, but chipped and fitted connections that are sealed with mortar may be installed when manufactured connections are not available. Laterals should be connected to mains so that their centerlines meet. Any curves in mains and

METHOD OF USING TARGETS FOR LAYING TILE


Top of target
6' above grade line
6' Staff
Hub stake

CRADLING TILE IN UNSTABLE SOILS

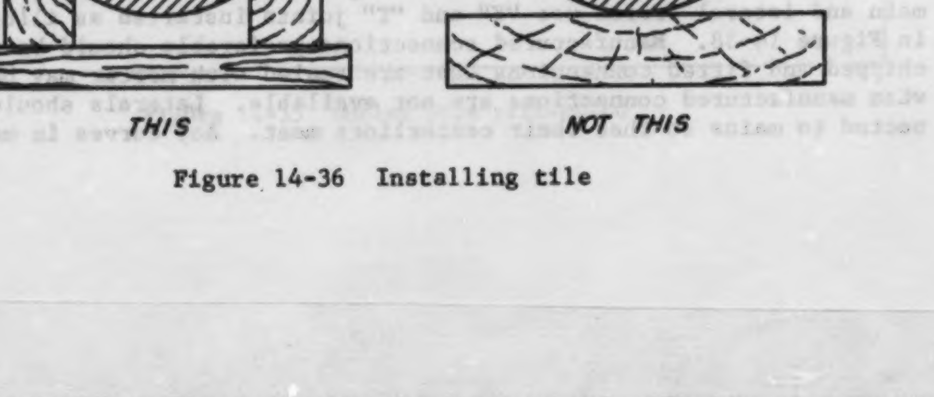
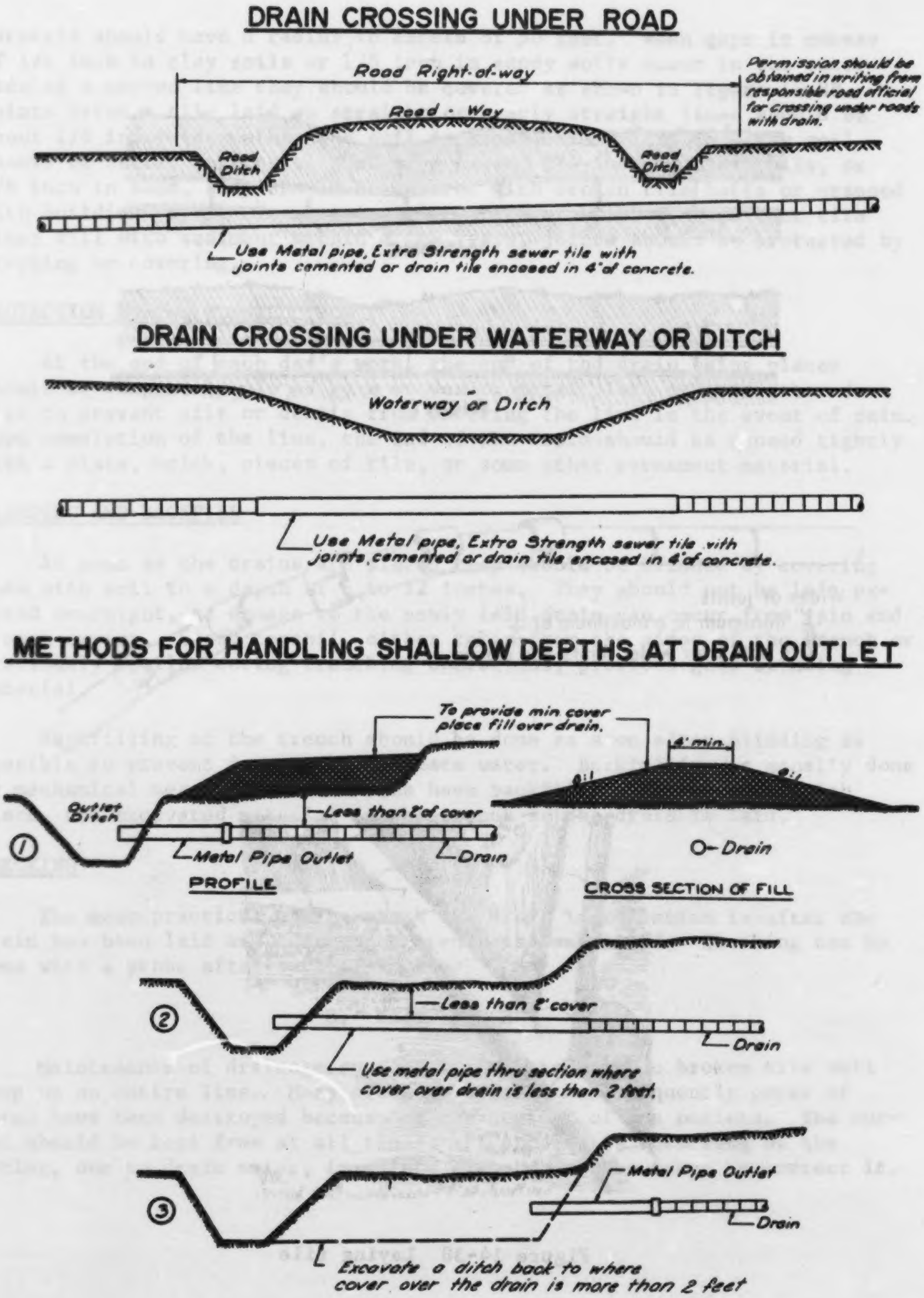

THIS
NOT THIS

Figure 14-36 Installing tile



DRAIN CROSSING UNDER ROAD

Road Right-of-way
Permission should be obtained in writing from responsible road official for crossing under roads with drain.
Road - Way
Road Ditch
Road Ditch
Use Metal pipe, Extra Strength sewer tile with joints cemented or drain tile encased in 4" of concrete.

DRAIN CROSSING UNDER WATERWAY OR DITCH

Waterway or Ditch
Use Metal pipe, Extra Strength sewer tile with joints cemented or drain tile encased in 4" of concrete.

METHODS FOR HANDLING SHALLOW DEPTHS AT DRAIN OUTLET

To provide min. cover place fill over drain.
Outlet Ditch
Less than 2' of cover
①
Metal Pipe Outlet
Drain
PROFILE
4' min.
6:1
6:1
O- Drain
CROSS SECTION OF FILL
②
Less than 2' cover
Drain
Use metal pipe thru section where cover over drain is less than 2 feet.
③
Metal Pipe Outlet
Drain
Excavate a ditch back to where cover over the drain is more than 2 feet

Figure 14-37 Drain crossings and outlets

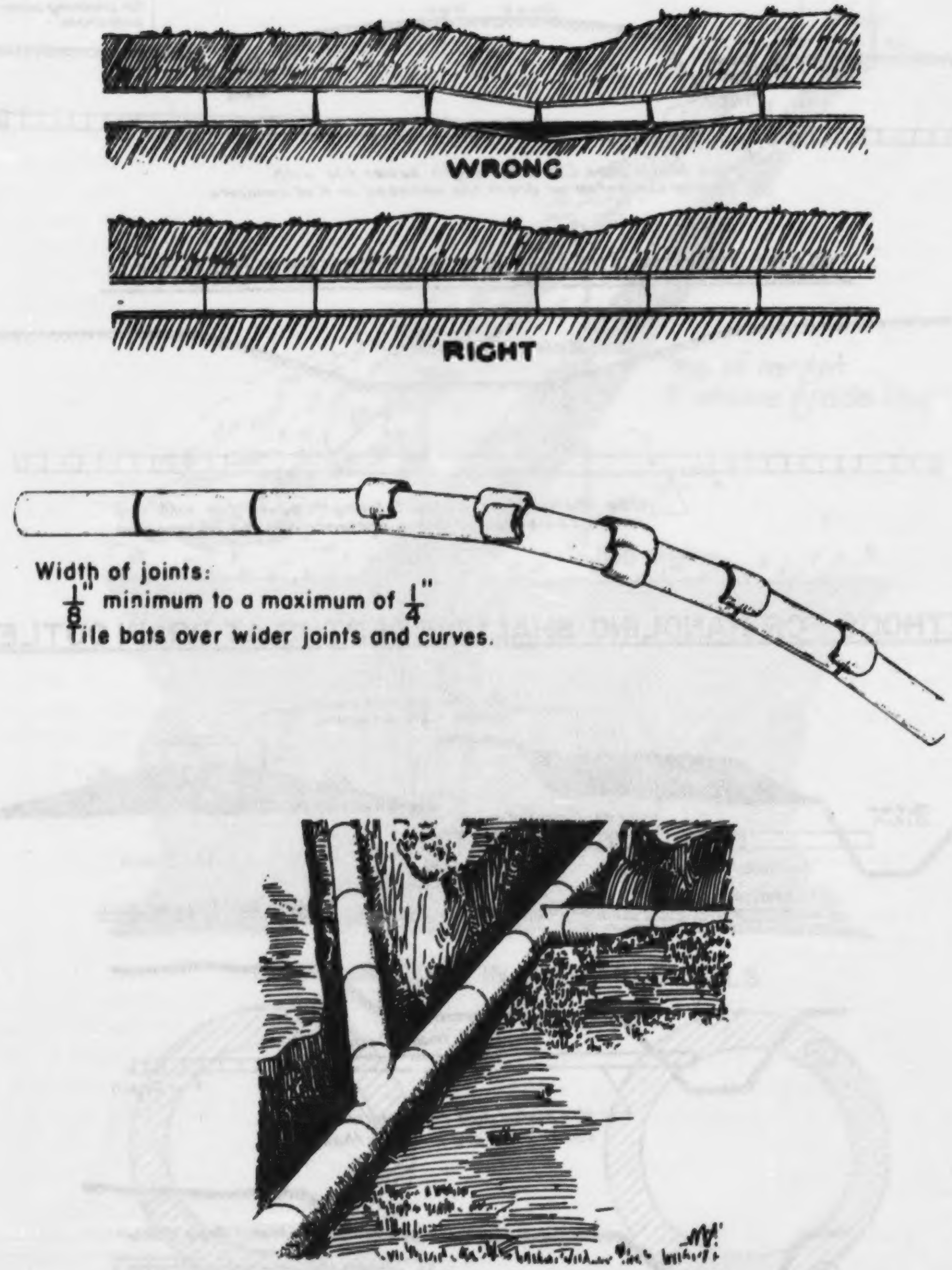

WRONG
RIGHT
Width of joints:
$\frac{1}{8}$" minimum to a maximum of $\frac{1}{4}$"
Tile bats over wider joints and curves.

Figure 14-38 Laying tile

laterals should have a radius in excess of 50 feet. When gaps in excess of 1/4 inch in clay soils or 1/8 inch in sandy soils occur in the outer side of a curved line they should be covered as shown in Figure 14-38. Joints between tile laid on straight or nearly straight lines should be about 1/8 inch wide unless the soil is sandy. Tile laid in sandy soil should be butted together. When gaps exceed 1/4 inch in clay soils, or 1/8 inch in sand, they should be covered with broken tile batts or wrapped with building paper. In certain soils where experience shows that tile lines fill with sediment within a few years, joints should be protected by wrapping or covering.

PROTECTION DURING CONSTRUCTION

At the end of each day's work, the end of the drain being placed should be completely closed by a wooden or metal plate or some other device to prevent silt or debris from entering the line in the event of rain. Upon completion of the line, the end of the drain should be closed tightly with a plate, brick, pieces of tile, or some other permanent material.

BLINDING AND BACKFILL

As soon as the drains are placed they should be blinded by covering them with soil to a depth of 6 to 12 inches. They should not be left exposed overnight, as damage to the newly laid drain can occur from rain and trench caving. Loose topsoil, either taken from the sides of the trench or previously spoiled during trenching operations, provides good blinding material.

Backfiling of the trench should be done as soon after blinding as possible to prevent damage from surface water. Backfilling is usually done by mechanical means. Some trenches have backfilling attachments which place the excavated material in the trench as the drain is laid.

CHECKING

The most practical way to check the drain installation is after the drain has been laid and before the trench is backfilled. Checking can be done with a probe after backfilling.

8. MAINTENANCE

Maintenance of drainage systems is important. One broken tile will stop up an entire line. Many drainage systems and frequently parts of farms have been destroyed because of the neglect of the outlets. The outlet should be kept free at all times. If erosion is occurring at the outlet, due to drain water, immediate steps should be taken to correct it.

9. MOLE DRAINAGE

Mole drains are cylindrical channels artificially produced in the subsoil without trenching from the surface. Various type plastic liners and methods of installation of the liners have been tried with varying success. The object of the lining is to extend the life of the mole channel.

Experience with the use of mole drainage in the United States is so variable that it is impractical to discuss its use here. Refer to the National Engineering Handbook, Section 16, for general information and to local guides for specific information.

10. CONTROLLED DRAINAGE

Controlled drainage is the control of ground water level by regulating the flow of water in the drainage system. It may be accomplished by use of structures which control the rate of flow or maintain a desired water surface elevation in natural or artificial channels.

Controlled drainage has been used primarily in organic and muck soils, but it is also applicable to mineral soils. Drainage systems of sufficient capacity to drain the fields in the spring may remove water needed for crop production in the summer. It is common practice to overcome this by retarding drainage in the dry part of the growing season. In addition to retarding drainage by means of dams and gates, water may be turned into the drainage system by pumping from wells or streams, or by diversion from irrigation systems, to raise the water table when crops require extra water. The addition of water to the drainage system from wells and streams is a form of subirrigation.

Dams for water control may be of many types. These structures normally have spillways fitted with stoplogs or gates for controlling the water level. Stop wells may be placed in the drains. These usually are a type of manhole fitted with stoplogs or adjustable metal slides to control the flow of water in the drains. Chapter 6 of this manual includes structures for water control.

11. DRAINAGE PUMPING PLANTS

GENERAL

Drainage pumping plants are used to remove excess surface or ground water from lowlands where it is impossible or uneconomical to obtain gravity outlets for drainage. They are also used at locations which have adequate outlets except during periods of prolonged high water. See Figure 14-39.

CONDITIONS UNDER WHICH PUMPING FOR SURFACE DRAINAGE MAY BE FEASIBLE

1. Bottom land or flatlands where the area is protected from flooding by means of dikes; where gravity drainage is restricted due to periodic high stages in the outlet; or where the outlet has inadequate capacity. Floodgates are installed to permit the maximum

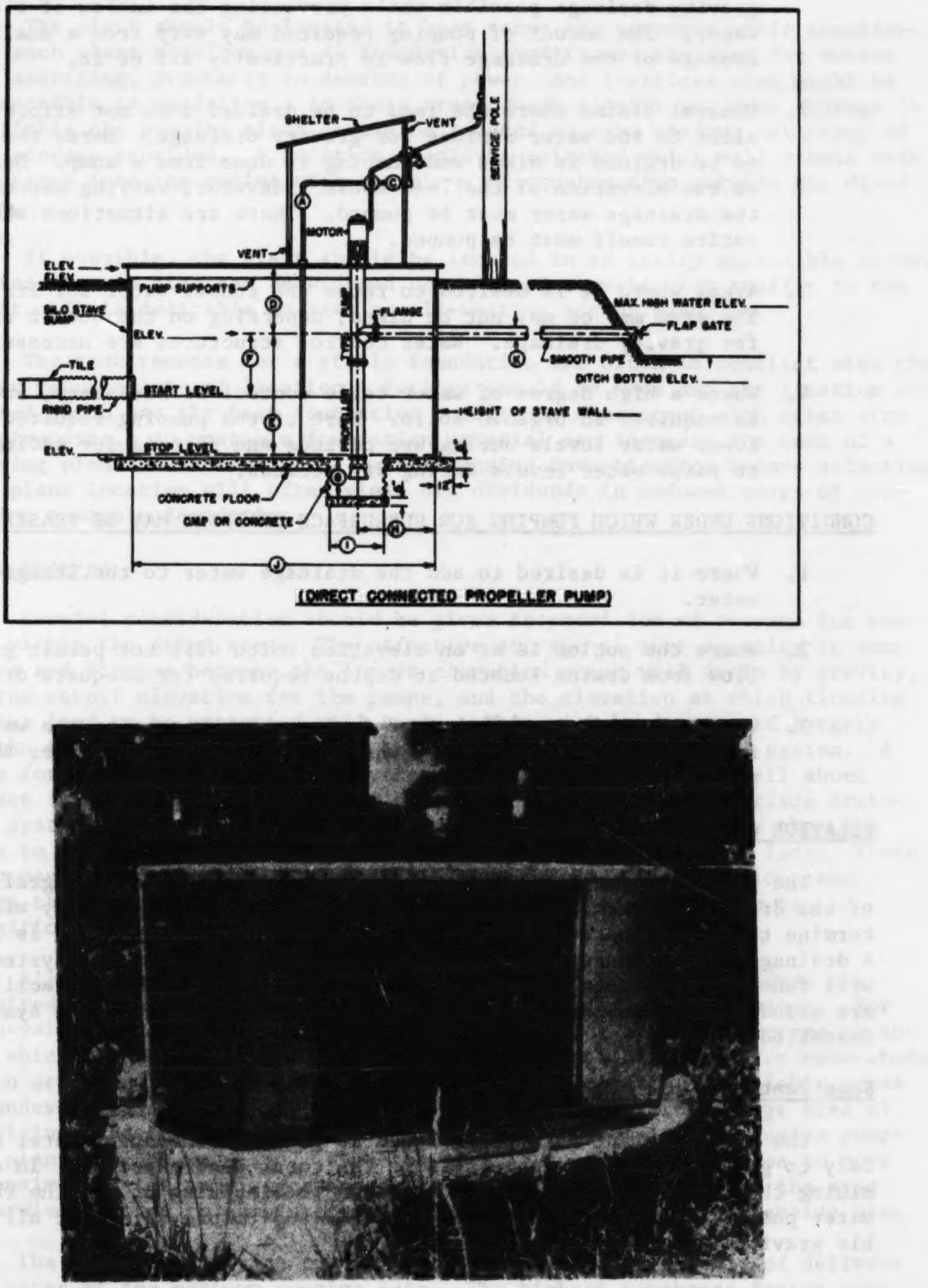

SHELTER
VENT
SERVICE POLE
A
B
C
MOTOR
VENT
ELEV.
ELEV.
PUMP SUPPORTS
D
PUMP
FLANGE
MAX. HIGH WATER ELEV.
SILO STAVE SUMP
ELEV.
FLAP GATE
F
K
SMOOTH PIPE
DITCH BOTTOM ELEV.
TILE
START LEVEL
RIGID PIPE
E
PROPELLER
HEIGHT OF STAVE WALL
ELEV.
STOP LEVEL
G
12"
CONCRETE FLOOR
GMP OR CONCRETE
H
I
J
(DIRECT CONNECTED PROPELLER PUMP)

Figure 14-39 Pump installation

gravity drainage possible while preventing the inflow of floodwater. The amount of pumping required may vary from a small percentage of the drainage flow to practically all of it.

2. Coastal plains where the land to be drained does not afford enough slope to the water surface for gravity drainage. Here, the land to be drained is diked and pumping is done from a sump. Depending on the elevation of the land above tidewater, varying amounts of the drainage water must be pumped. There are situations where the entire runoff must be pumped.
3. Areas where it is desired to reuse the runoff water for irrigation. The area may or may not be diked, depending on the outlet situation for gravity drainage. Water control structures are necessary.
4. Where a high degree of water table control is necessary, such as is required in organic soils. Part of the pumping required is to lower water levels during wet periods and part is for adding water to raise water levels during dry periods.

CONDITIONS UNDER WHICH PUMPING FOR SUBSURFACE DRAINAGE MAY BE FEASIBLE

1. Where it is desired to add the drainage water to the irrigation water.
2. Where the outlet is at an elevation which will not permit gravity flow from drains located at depths required for adequate drainage.
3. Where the indicated method of drainage is by pumping the water from an underlying aquifer, which may or may not be under artesian pressure.

RELATION OF PUMPING PLANT TO DRAINAGE SYSTEM

The pumping plant should be planned and designed as an integral part of the drainage system. The reconnaissance or preliminary survey will determine the condition of the drainage outlet and whether pumping is required. A drainage system where the pumping plant is designed into the system usually will function much more efficiently than one where the pumping facilities are added because the outlet is found to be inadequate after the system is installed.

Some Features Which Require Coordination

The pumping plant must be designed to pump the amount of water necessary to give adequate drainage against the total head expected. In determining this, consideration should be given to disposing of all the runoff water possible by diversion around the area and to providing for all possible gravity flow through floodgates.

The plant should be located to best serve the purposes while considering such plant requirements as foundation conditions, the need for access for servicing, proximity to sources of power, and locations that might be susceptible to vandalism. In those areas where significant sump storage is available the pumping plant should be located to take maximum advantage of the storage provided. A location should be selected which will permit safe discharge into the outlet with a minimum of construction outside the diked area.

If possible, the plant should be located in an easily accessible place. Ordinarily the dike can be widened to accommodate vehicular traffic to the plant. It is desirable to have an all-weather access road.

The requirements for a stable foundation are often in conflict with the other requirements of location. Borings should be made and the location selected which has the best foundation conditions consistent with other site requirements. An unstable foundation material can increase the cost of a pumping plant considerably. A more intensive investigation before selecting the plant location will often yield big dividends in reduced costs of providing a stable foundation.

Sump Storage

Careful consideration should be given to provision of storage for runoff within the diked area. The effective storage is that capacity in sump areas and ditches between the lowest elevation which will drain by gravity, or the cutoff elevation for the pumps, and the elevation at which flooding of the land to be protected will begin. This will be determined largely by the topography of the project area and the type of drainage system. A sump for a subsurface drainage system may be only a circular well about 8 feet in diameter with 2 feet of effective storage. For a surface drainage system there may be a sizeable area near the outlet, lower than the area to be drained, which can be used for storage without crop loss. There also may be borrow pits of appreciable size for dike construction; and often the drainage ditches will have enough storage capacity to be significant.

All of the storage capacity available should be used to reduce the required pumping capacity, considering the economics of the project. For high-value, highly developed cultivated land, about the only storage capacity which may be available will be that in the open ditches. For watersheds which are used for low-value crops and which may contain appreciable areas of undeveloped land, it may be desirable to devote a rather large area of low-lying land to sump storage with the result that a less expensive pumping plant will be required. When the need is to develop the area to more intensive use the pumping capacity may be increased and some of the area otherwise devoted to sump storage can be developed for more intensive use.

The ditches supplying runoff to the pumps must be capable of delivering water at the maximum pumping rate. The highest roughness factor considered likely to occur should be used to determine the ditch size for this requirement.

DETERMINATION OF ECONOMIC JUSTIFICATION OF PUMPING PLANT

Frequently there is a question as to whether areas protected against flooding by dikes and floodgates should be provided with a pumping plant to remove interior drainage during periods when the floodgates are closed. This requires a frequency study of precipitation and flood stage records, a determination of the project area which will be flooded without a pumping plant and the resulting damages. The study required for the justification of a pumping plant should be based on a comparison of its cost with the damages which may be expected without it.

PUMPING FROM SUBSURFACE AQUIFERS

In those systems where drainage is to be effected by pumping from an underlying aquifer, location of the wells and pumps must be based on an extensive subsurface investigation. This investigation must determine the practicability of effecting the required lowering of the water table by pumping the aquifer and also the most suitable location for the wells to accomplish the objectives. Disposal of the drainage water may be either into the irrigation system or through shallow surface ditches to a drainage outlet. In either case location of the well would be based primarily on requirements for pumping the aquifer instead of conditions for discharge of the effluent.

BASIC INFORMATION REQUIRED FOR PLANT DESIGN

In order to correlate the design of the pumping plant with the rest of the drainage system the Service should obtain and provide the basic data on which the design of the plant is based. For the smaller plants this may result in providing the owner sufficient data to enable him to purchase the proper equipment and make the installation. But for the larger plants, the details of equipment design, selection, and installation usually require specialized engineering assistance. In these cases the Service should determine the operational requirements for the plant and provide consulting service to the engineering firm selected by the owners to design the plant and supervise its construction.

The amount of data provided by the Service will vary according to specific arrangements. As a general rule, data on the following items should be provided:

1. Location of plant - detailed topography and data on foundation investigations may or may not be provided by the Service.
2. Pump capacity required - design removal rate less available storage.
3. Maximum, minimum, and average static heads - based on stage-frequency analysis of the outlet.

The maximum static head is the elevation of the maximum stage in the outlet minus the optimum elevation in the suction bay. Efficiency at this head may be lower than is required at the average head.

The minimum static head is the difference between the mean monthly minimum stage in the outlet and the optimum stage in the suction bay. Where multiple pumping units are required, at lease one unit should have a high efficiency at this head.

Average static head is the difference between the average monthly stage in the outlet and the optimum stage in the suction bay, weighted according to the amounts of runoff to be expected for the respective months. The plant should operate at peak efficiency for this stage.

4. Recommended type, number, and size of pumps required. For low heads, up to 15 to 20 feet, the axial flow pump is recommended. Above that and up to 40 to 50 feet, the mixed flow pump is recommended. For large installations at least two pumps should be recommended with the relative size based on operational requirements. For average conditions one of the two pumps should have about twice the capacity of the other. A 3-unit plant gives good flexibility of operation. Sizes recommended should be based on holding velocities in the discharge pipe at 8 to 10 feet per second for the design capacity.

5. Recommended cut-on and cutoff elevations for each unit.

6. Schematic layout of the proposed plant. This should include suggestions for layout and appurtenant facilities which should be considered in a well designed plant - such items as the installation of discharge pipes over dikes, trash racks, siphon breakers, equipment for automatic control of operation, access road, etc. - should be indicated.

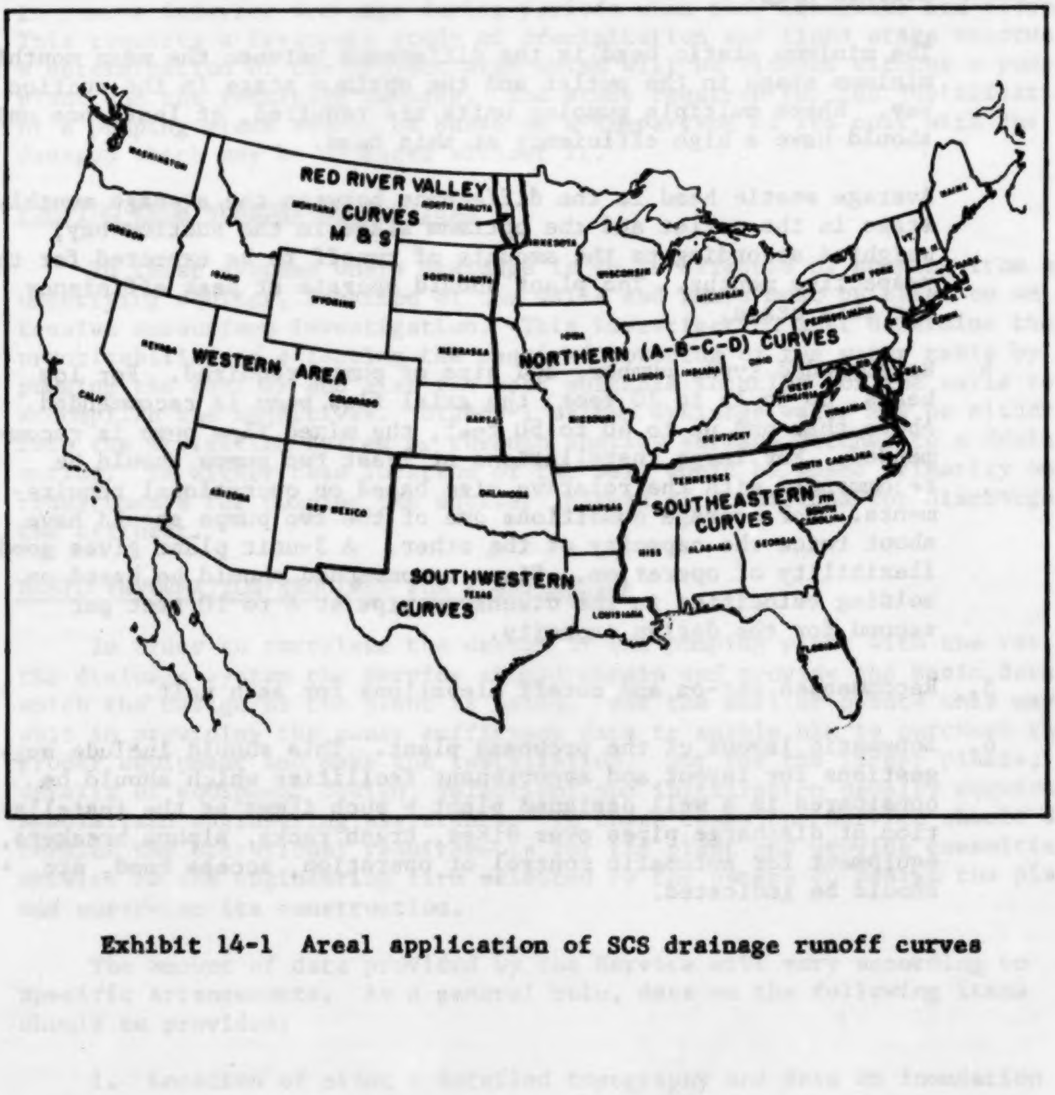
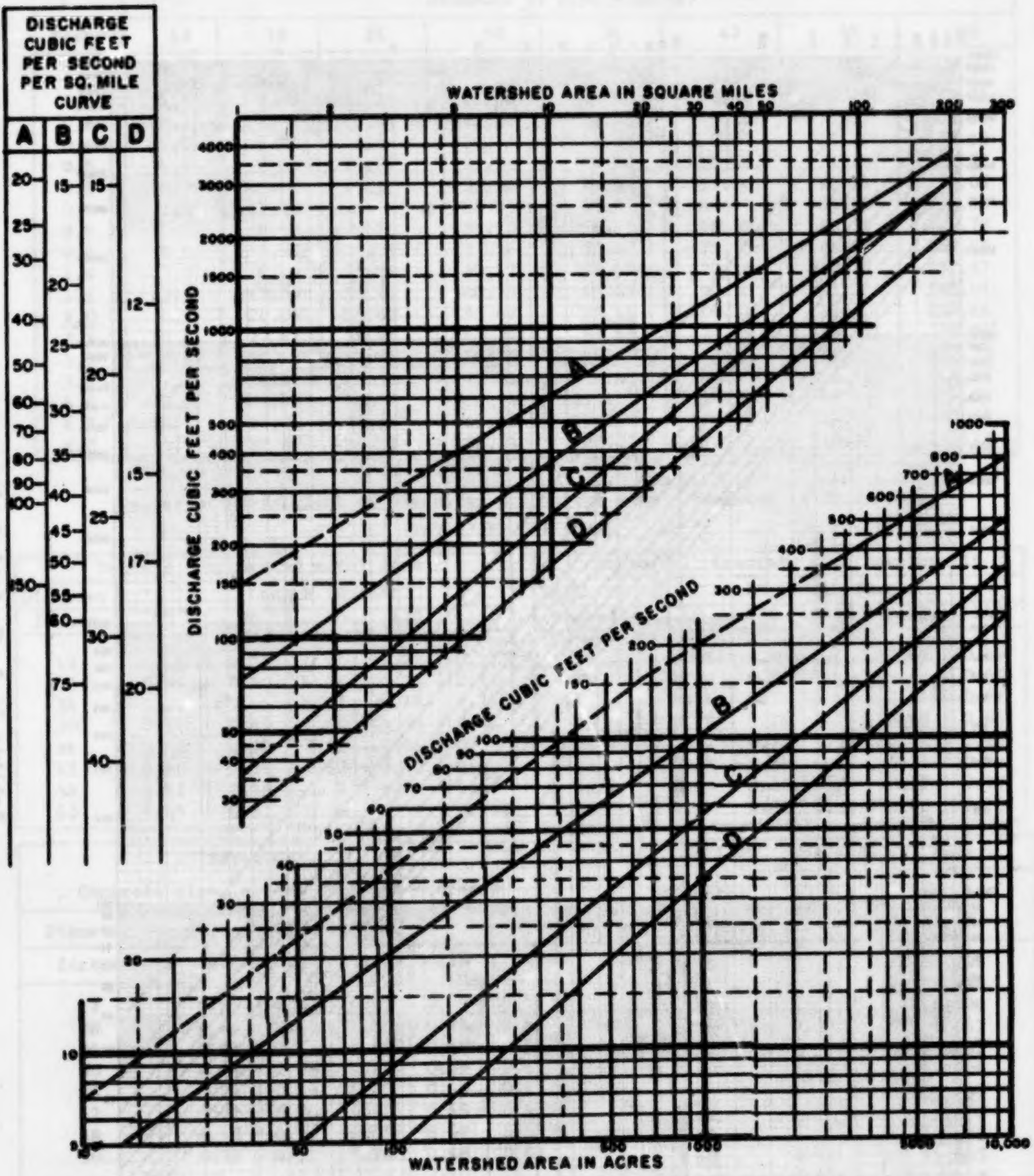

WASHINGTON
OREGON
IDAHO
MONTANA
NORTH DAKOTA
RED RIVER VALLEY
CURVES
M & S
MINNESOTA
WISCONSIN
MICHIGAN
NEW YORK
MAINE
VT.
N.H.
MASS.
CONN.
PENNSYLVANIA
SOUTH DAKOTA
WYOMING
IOWA
NEVADA
WESTERN AREA
NEBRASKA
NORTHERN (A-B-C-D) CURVES
ILLINOIS
INDIANA
OHIO
WEST VIRGINIA
VIRGINIA
CALIF.
UTAH
COLORADO
KANSAS
MISSOURI
KENTUCKY
NORTH CAROLINA
TENNESSEE
ARIZONA
NEW MEXICO
OKLAHOMA
ARKANSAS
SOUTHEASTERN
CURVES
SOUTH CAROLINA
MISS.
ALABAMA
GEORGIA
SOUTHWESTERN
CURVES
TEXAS
LOUISIANA
FLORIDA

Exhibit 14-1 Areal application of SCS drainage runoff curves



GENERAL USE OF CURVES - FOR FLAT LANDS. AVERAGE SLOPE LESS THAN 25 FEET PER MILE.

CURVE A - For good protection from overflow (not maximum flood runoff).

CURVE B - For excellent drainage.

CURVE C - For good agricultural drainage; basic drainage curve for grain crops.

CURVE D - For fair agricultural drainage and drainage improved pastures. For specific uses see design criteria or technical standards.

Exhibit 14-2 Drainage runoff curves for Northern humid areas

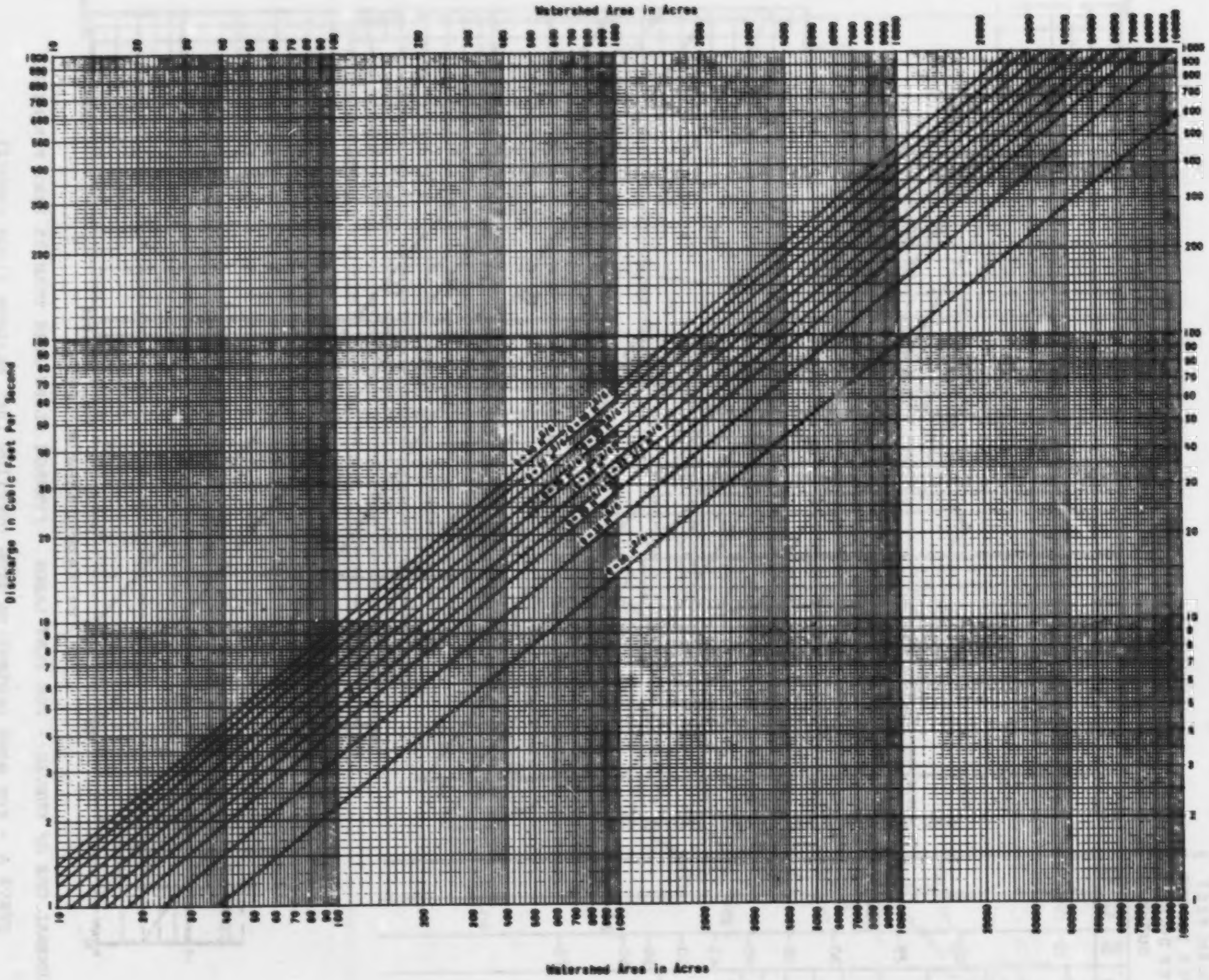


Exhibit 14-3 Typical drainage curves

Table A Values of $a\sqrt{2gh}$ for circular pipes								
h	Diameter of pipe - inches							
feet	12	18	24	30	36	42	48	60
0.1	2.0	4.48	7.96	12.44	17.91	24.38	31.84	49.75
0.2	2.8	6.33	11.26	17.60	25.34	34.49	45.05	70.39
0.3	3.4	7.77	13.81	21.58	31.07	42.28	55.23	86.30
0.4	4.0	8.96	15.93	24.88	35.83	48.77	63.70	99.53
0.5	4.4	10.00	17.82	27.83	40.08	54.55	71.25	111.33
0.6	4.9	10.98	19.53	30.51	43.94	59.80	78.11	122.05
0.7	5.3	11.86	21.09	32.95	47.45	64.59	84.36	131.81
0.8	5.6	12.67	22.53	35.20	50.61	68.98	90.10	140.78
0.9	6.0	13.45	22.91	37.36	53.80	73.23	95.64	149.44
1.0	6.3	14.17	25.20	39.37	56.69	77.16	100.78	157.47
1.5	7.7	17.36	30.87	48.23	69.45	94.53	123.46	192.91
2.0	8.9	20.04	35.63	53.67	80.16	109.10	142.50	222.66
2.5	10.0	22.41	39.84	62.24	89.63	121.99	159.34	248.97
3.0	10.9	24.55	43.65	68.19	98.20	133.65	174.55	272.75
3.5	11.8	26.51	47.15	73.66	106.07	144.36	188.55	294.62
4.0	12.6	28.34	50.40	78.74	113.39	154.32	201.56	314.95
4.5	13.4	30.06	53.45	83.50	120.24	163.65	213.75	333.99
5.0	14.1	31.69	56.35	88.03	126.77	172.53	225.35	352.11

Values of Coefficient of Discharge C **From King's Handbook of Hydraulics**

(Tables B; C-1 and C-2)

Table B Corrugated metal pipe					
Diameter	Length in feet				
inches	60	80	100	120	140
12	0.36	0.32	0.29	0.27	0.25
18	0.44	0.40	0.36	0.33	0.31
24	0.50	0.45	0.41	0.38	0.36
30	0.54	0.49	0.46	0.43	0.40
36	0.58	0.53	0.49	0.46	0.44
42	0.60	0.56	0.52	0.49	0.46
48	0.62	0.58	0.54	0.51	0.49
60	0.66	0.61	0.58	0.55	0.53

Table C-1 Concrete pipe-beveled lip					
Diameter	Length in feet				
inches	60	80	100	120	140
12	0.61	0.56	0.52	0.49	0.46
18	0.70	0.65	0.61	0.58	0.55
24	0.75	0.71	0.67	0.64	0.61
30	0.79	0.75	0.71	0.68	0.66
36	0.81	0.78	0.74	0.71	0.69
42	0.83	0.80	0.77	0.74	0.72
48	0.85	0.82	0.79	0.77	0.75
60	0.87	0.84	0.82	0.80	0.78

Table C-2 Concrete pipe, square cornered entrance					
Diameter	Length in feet				
inches	60	80	100	120	140
12	0.59	0.54	0.51	0.48	0.45
18	0.65	0.61	0.58	0.55	0.53
24	0.69	0.65	0.62	0.60	0.58
30	0.71	0.68	0.65	0.63	0.61
36	0.72	0.69	0.67	0.65	0.63
42	0.72	0.70	0.68	0.66	0.65
48	0.72	0.70	0.69	0.67	0.66
60	0.72	0.71	0.70	0.68	0.67

Table D Pipe size vs. area	
Diameter inches	Area - a sq.ft.
6	0.196
8	0.349
12	0.785
18	1.767
24	3.142
30	4.909
36	7.069
42	9.621
48	12.566
60	19.635

$$v = \frac{Q}{a}$$

Where v is velocity of flow in feet per second; Q is cubic feet per second, and a is sq. ft. of pipe section.

Sheet 1 of 2

Exhibit 14-4 Tables for computing culvert discharge
$Q = Ca\sqrt{2gh}$ and minimum surcharge h_1

Table E Minimum surcharge (h_1) for corrugated metal pipe

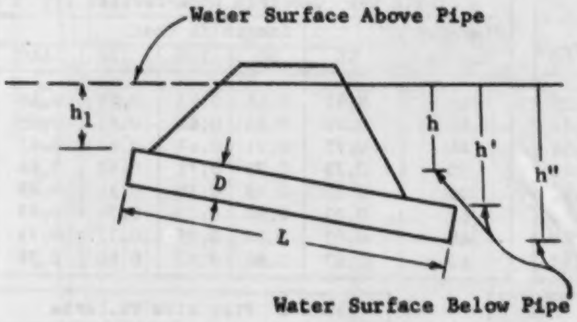
h_1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	Vel.	2.13	3.01	3.69	4.27	4.76	5.22	5.64	6.03	6.40
1.0	6.74	7.07	7.39	7.69	7.98	8.26	8.59	8.79	9.04	9.29
2.0	9.53	9.77	10.00	10.22	10.44	10.65	10.87	11.08	11.28	11.48
3.0	11.67	11.87	12.06	12.25	12.43	12.61	12.79	12.96	13.14	13.31
4.0	13.48	13.65								

h_1 in feet = $0.022\ v^2$

Table F Minimum surcharge (h_1) for concrete pipe

h_1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	Vel.	2.42	3.41	4.18	4.85	5.42	5.94	6.34	6.86	7.27
1.0	7.67	8.04	8.40	8.76	9.08	9.39	9.70	10.00	10.29	10.57
2.0	10.87	11.11	11.38	11.63	11.88	12.12	12.37	12.58	12.84	13.06
3.0	13.28	13.50	13.72	13.94	14.14	14.34	14.55	14.75	14.95	15.15
4.0	15.34	15.53	15.72	15.88	16.09	16.26	16.45	16.63		

h_1 in feet = $0.017\ v^2$



h_1 = Surcharge at culvert entrance.
$h_1 > 0.22\ v^2$ for C.M.P.
$h_1 > 0.17\ v^2$ for concrete pipe
For free outlet, use h' for h;
h' may be approximated as h" less an assumed vertical diameter.

Example: It is required to carry 44 cfs through a CMP culvert 60 ft. long with submerged outlet where the difference h in water surface above and below the pipe is 2.0 feet.

Try 36" diam. Enter Table A with a 2.0' head and 36" diam. Find $a\sqrt{2gh} = 80.16$. Enter Table B, CMP with 36" diam. and 60' length L. find C = 0.58. 80.16 x 0.58 = 46.5 cfs. The 36" will do. Enter Table D, find area of 36" = 7.069 sq.ft. 44 + 7.069 = 6.22 fps velocity. Enter Table E with velocity 6.22 fps. find minimum surcharge h_1 of 0.85'. The top of the 36" CMP must be set 0.85' below the water surface or hydraulic gradeline above the culvert.

Sheet 2 of 2

Exhibit 14-4 Tables for computing culvert discharge
$Q = Ca\sqrt{2gh}$ and minimum surcharge h_1

Chart Number	Bottom Width (feet)	Side Slopes (ratio)	Channel Slopes (ft./ft.)	Depth Range (feet)
ES-Water Surface Profiles				
125	1-100	0:1	Any slope	0.2-30.0
127	1-75	1:1	See T.R. 15	0.2-30.0
128	1-140	1½:1		0.2-30.0
129	1-300	2:1		0.2-30.0
130	1-75	2½:1		0.2-30.0
131	1-300	3:1		0.2-30.0
Lincoln Cartographic Drawings				
5,P-23015.1	0-100	1:1	.00005-.008	1.0-11.5
5,P-23015.2	0-100	1½:1	.00005-.008	1.0-11.5
5,P-23015.3	0-100	2:1	.00005-.008	1.0-11.5
5,P-23015.4	0-100	2½:1	.00005-.008	1.0-11.5
5,P-23015.5	0-100	3:1	.00005-.008	1.0-11.5
5,P-23015.6	0-100	4:1	.00005-.008	1.0-11.5
Fort Worth Cartographic Drawings				
4-L-8094	V	3:1	.00005-.002	1.0-3.0
4-L-8095	V	4:1	.00005-.002	1.0-2.5
4-L-19891	3	1½:1	.00005-.002	1.0-1.9
4-R-10249	3	1½:1	.00005-.002	2.0-6.1
4-R-10250	3	2:1	.00005-.004	2.0-6.1
4-R-10251	4	1½:1	.00005-.002	2.0-6.1
4-R-10252	4	2:1	.00005-.002	2.0-6.6
4-L-12747	4	4:1	.00005-.002	1.0-3.4
4-L-19948	6	1½:1	.00005-.002	1.0-5.4
4-L-19948	6	2:1	.00005-.0025	1.0-5.4
4-L-15435	8	1½:1	.00005-.003	1.5-7.9
4-L-15436	8	2:1	.00005-.003	1.5-7.8
4-L-16263	10	1½:1	.00005-.001	3.0-10.0
4-L-16262	12	1½:1	.00005-.001	3.0-11.0
4-L-16261	14	1½:1	.00005-.001	3.0-11.9

Exhibit 14-5 Available ditch design charts

Values of "V" and "Q" for Trapezoidal Ditches with 4-foot Bottom Side Slopes 2:1 n = .045

Depth in Ft.	2.0		2.1		2.2		2.3		2.4		2.5		2.6	
X-Sec. Area	16.00		17.22		18.48		19.78		21.12		22.50		23.92	
Hyd. Radius	1.24		1.29		1.34		1.38		1.43		1.48		1.53	
S (Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.27	4.3	.28	4.8	.28	5.2	.29	5.7	.30	6.3	.30	6.8	.31	7.4
.00010	.38	6.1	.39	6.7	.40	7.4	.41	8.1	.42	8.9	.43	9.7	.44	10.5
.00015	.47	7.5	.48	8.2	.49	9.1	.50	9.9	.51	10.9	.53	11.8	.54	12.9
.00020	.54	8.6	.55	9.5	.57	10.5	.58	11.5	.59	12.5	.61	13.7	.62	14.8
.00025	.60	9.6	.62	10.6	.63	11.7	.65	12.8	.66	14.0	.68	15.3	.69	16.6
.00030	.66	10.5	.68	11.6	.69	12.8	.71	14.0	.73	15.3	.74	16.7	.76	18.2
.00035	.71	11.4	.73	12.6	.75	13.8	.77	15.2	.79	16.6	.80	18.1	.82	19.6
.00040	.76	12.2	.78	13.4	.80	14.8	.82	16.2	.84	17.7	.86	19.3	.88	21.0
.00045	.81	12.9	.83	14.3	.84	15.5	.87	17.2	.89	18.8	.91	20.5	.93	22.3
.00050	.85	13.6	.87	15.0	.89	16.5	.92	18.1	.94	19.8	.96	21.6	.98	23.4
.00055	.89	14.3	.92	15.8	.93	17.2	.96	19.0	.98	20.8	1.01	22.6	1.03	24.6
.00060	.93	14.9	.96	16.5	.98	18.1	1.00	19.8	1.03	21.7	1.05	23.7	1.07	25.7
.00065	.97	15.5	1.00	17.1	1.02	18.9	1.04	20.7	1.07	22.6	1.09	24.6	1.12	26.7
.00070	1.01	16.1	1.03	17.8	1.06	19.6	1.08	21.4	1.11	23.4	1.14	25.5	1.16	27.8
.00075	1.04	16.7	1.07	18.4	1.10	20.3	1.12	22.2	1.15	24.3	1.18	26.4	1.20	28.7
.00080	1.08	17.2	1.10	19.0	1.13	20.9	1.16	22.9	1.19	25.1	1.21	27.3	1.24	29.6
.00085	1.11	17.7	1.14	19.6	1.17	21.6	1.19	23.6	1.22	25.8	1.25	28.2	1.28	30.6
.00090	1.14	18.2	1.17	20.2	1.20	22.2	1.23	24.3	1.26	26.6	1.29	29.0	1.32	31.5
.00095	1.17	18.8	1.20	20.7	1.23	22.8	1.26	25.0	1.29	27.3	1.32	29.7	1.35	32.3
.00100	1.20	19.2	1.23	21.3	1.27	23.4	1.30	25.6	1.33	28.0	1.36	30.5	1.39	33.2
.0011	1.26	20.2	1.30	22.3	1.33	24.5	1.36	26.9	1.39	29.4	1.42	32.0	1.45	34.8
.0012	1.32	21.1	1.35	23.3	1.39	25.6	1.42	28.1	1.45	30.7	1.49	33.4	1.52	36.3
.0013	1.37	21.9	1.41	24.2	1.44	26.7	1.48	29.2	1.51	32.0	1.55	34.8	1.58	37.8
.0014	1.42	22.8	1.46	25.2	1.50	27.7	1.53	30.3	1.57	33.2	1.61	36.1	1.64	39.2
.0015	1.47	23.6	1.51	26.0	1.55	28.6	1.59	31.4	1.62	34.3	1.66	37.4	1.70	40.6
.0016	1.52	24.3	1.56	26.9	1.60	29.6	1.64	32.4	1.68	35.4	1.72	38.6	1.75	41.9
.0017	1.57	25.1	1.61	27.7	1.65	30.5	1.69	33.4	1.73	36.5	1.77	39.8	1.81	43.2
.0018	1.61	25.8	1.66	28.5	1.70	31.4	1.74	34.4	1.78	37.6	1.82	41.0	1.86	44.5
.0019	1.66	26.5	1.70	29.3	1.74	32.2	1.79	35.3	1.83	38.6	1.87	42.1	1.91	45.7
.0020	1.70	27.2	1.75	30.1	1.78	32.9	1.83	36.2	1.88	39.6	1.92	43.2	1.96	46.9

4-R-10252

Exhibit 14-6 Ditch design tables
(Sheet 1 of 10)

Values of "V" and "Q" for Trapezoidal Ditches with 4-foot Bottom Side Slopes 2:1 n = .045

Depth in Ft.	2.7		2.8		3.0		3.2		3.4		3.6		3.8	
X-Sec. Area	25.38		26.88		30.00		33.28		36.72		40.32		44.08	
Hyd. Radius	1.58		1.63		1.72		1.82		1.91		2.01		2.10	
S (Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.32	8.0	.32	8.7	.34	10.1	.35	11.6	.36	13.2	.37	15.0	.38	16.8
.00010	.45	11.4	.46	12.3	.47	14.2	.49	16.4	.51	18.6	.53	21.2	.54	23.8
.00015	.55	13.9	.56	15.1	.58	17.4	.60	20.1	.62	22.8	.64	26.0	.66	29.2
.00020	.63	16.1	.65	17.4	.67	20.1	.70	23.2	.72	26.4	.74	30.0	.77	33.7
.00025	.71	17.9	.72	19.4	.75	22.5	.78	25.9	.80	29.5	.83	33.5	.86	37.7
.00030	.78	19.7	.79	21.3	.82	24.6	.85	28.4	.88	32.3	.91	36.7	.94	41.3
.00035	.84	21.2	.86	23.0	.89	26.6	.92	30.7	.95	34.9	.98	39.7	1.01	44.6
.00040	.90	22.7	.91	24.6	.95	28.4	.98	32.8	1.02	37.3	1.05	42.4	1.08	47.7
.00045	.95	24.1	.97	26.1	1.01	30.2	1.04	34.7	1.08	39.6	1.12	45.0	1.15	50.6
.00050	1.00	25.4	1.02	27.5	1.06	31.8	1.10	36.6	1.14	41.7	1.18	47.4	1.21	53.3
.00055	1.05	26.7	1.07	28.8	1.11	33.3	1.15	38.4	1.19	43.7	1.23	49.7	1.27	55.9
.00060	1.10	27.8	1.12	30.1	1.16	34.8	1.21	40.1	1.24	45.7	1.29	51.9	1.33	58.4
.00065	1.15	29.0	1.17	31.3	1.21	36.2	1.26	41.8	1.30	47.6	1.34	54.1	1.38	60.8
.00070	1.18	30.1	1.21	32.5	1.25	37.6	1.30	43.3	1.34	49.3	1.39	56.1	1.43	63.1
.00075	1.23	31.0	1.25	33.7	1.30	38.9	1.35	44.9	1.39	51.1	1.44	58.1	1.48	65.3
.00080	1.27	32.1	1.29	34.8	1.34	40.2	1.39	46.3	1.44	52.7	1.49	60.0	1.53	67.4
.00085	1.31	33.1	1.33	35.8	1.38	41.4	1.43	47.7	1.48	54.4	1.53	61.8	1.58	69.5
.00090	1.34	34.1	1.37	36.9	1.42	42.7	1.48	49.1	1.52	56.0	1.58	63.7	1.62	71.5
.00095	1.38	35.0	1.41	37.9	1.46	43.8	1.52	50.5	1.57	57.5	1.62	65.3	1.67	73.5
.00100	1.42	35.9	1.45	38.8	1.50	44.9	1.56	51.8	1.61	59.0	1.66	67.0	1.71	75.4
.0011	1.49	37.7	1.52	40.8	1.57	47.2	1.63	54.3	1.69	61.9	1.77	71.5	1.79	79.1
.0012	1.55	39.3	1.58	42.6	1.64	49.3	1.70	56.7	1.76	64.6	1.82	73.4	1.87	82.6
.0013	1.61	41.0	1.65	44.3	1.71	51.3	1.77	59.0	1.83	67.3	1.90	76.5	1.95	86.0
.0014	1.68	42.3	1.71	46.0	1.77	53.2	1.84	61.3	1.90	69.8	1.97	79.3	2.02	89.2
.0015	1.73	43.8	1.77	47.6	1.84	55.1	1.91	63.8	1.97	72.2	2.04	82.1	2.10	92.4
.0016	1.79	45.4	1.83	49.1	1.90	56.9	1.97	65.5	2.03	74.6	2.10	84.8	2.16	95.4
.0017	1.85	46.8	1.88	50.6	1.95	58.6	2.03	67.5	2.09	76.9	2.17	87.4	2.23	98.3
.0018	1.90	48.2	1.94	52.1	2.01	60.3	2.09	69.5	2.16	79.1	2.23	90.0	2.30	101.2
.0019	1.95	49.5	1.99	53.5	2.07	62.0	2.15	71.4	2.21	81.3	2.29	92.4	2.36	103.9
.0020	2.00	50.8	2.04	54.9	2.12	63.6	2.20	73.2	2.27	83.4	2.35	94.8	2.42	106.6

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Exhibit 14-6 Ditch design tables
(Sheet 2 of 10)

Values of "V" and "Q" for Trapezoidal Ditches with 4-foot Bottom Side Slopes 2:1 n = .045

Depth in Ft.	4.0		4.2		4.4		4.6		4.8		5.0		5.2	
X-Sec. Area	48.00		52.08		56.32		60.72		65.28		70.00		74.88	
Hyd. Radius	2.19		2.29		2.38		2.47		2.56		2.66		2.75	
S (Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.39	18.2	.41	21.1	.42	23.4	.43	25.9	.44	28.5	.45	31.4	.46	41.0
.00010	.56	26.7	.57	29.8	.59	33.1	.60	36.6	.62	40.3	.63	44.4	.65	48.5
.00015	.68	32.7	.70	36.6	.72	40.6	.74	44.9	.76	49.4	.78	54.3	.79	59.5
.00020	.78	37.3	.81	42.2	.83	46.9	.85	51.8	.87	57.0	.90	62.7	.92	68.6
.00025	.88	42.2	.91	47.2	.93	52.4	.95	57.9	.98	63.7	1.00	70.1	1.02	76.7
.00030	.96	46.3	.99	51.7	1.02	57.4	1.04	63.4	1.07	69.8	1.10	76.8	1.12	84.0
.00035	1.04	50.0	1.07	55.8	1.10	62.0	1.13	68.5	1.16	75.4	1.19	83.0	1.21	90.8
.00040	1.11	53.4	1.15	59.7	1.18	66.2	1.21	73.2	1.24	80.6	1.27	88.7	1.30	97.0
.00045	1.18	56.6	1.22	63.3	1.25	70.2	1.28	77.7	1.31	85.5	1.34	94.1	1.37	102.9
.00050	1.24	59.7	1.28	66.8	1.32	74.1	1.35	81.9	1.38	90.2	1.42	99.2	1.45	108.4
.00055	1.31	62.6	1.34	70.0	1.38	77.7	1.41	85.9	1.45	94.5	1.49	104.0	1.52	113.7
.00060	1.36	65.4	1.40	73.1	1.44	81.1	1.48	89.7	1.51	98.7	1.55	108.6	1.59	118.8
.00065	1.42	68.1	1.46	76.1	1.50	84.5	1.54	93.3	1.57	102.8	1.62	113.1	1.65	123.7
.00070	1.47	70.7	1.52	79.0	1.56	87.6	1.60	96.9	1.63	106.7	1.68	117.4	1.71	128.3
.00075	1.52	73.2	1.57	81.8	1.61	90.7	1.65	100.3	1.69	110.4	1.74	121.5	1.77	132.8
.00080	1.57	75.5	1.62	84.4	1.66	93.7	1.71	103.5	1.75	114.0	1.79	125.4	1.83	137.2
.00085	1.62	77.9	1.67	87.0	1.71	96.5	1.76	106.7	1.80	117.6	1.85	129.3	1.89	141.4
.00090	1.67	80.1	1.72	89.6	1.76	99.4	1.81	109.8	1.85	120.9	1.90	133.1	1.94	145.5
.00095	1.72	82.3	1.77	92.0	1.81	102.1	1.86	112.8	1.90	124.2	1.95	136.7	2.00	149.5
.00100	1.76	84.3	1.81	94.4	1.86	104.7	1.91	115.7	1.95	127.4	2.00	140.2	2.05	153.4
.0011	1.85	88.6	1.90	99.0	1.95	109.9	2.00	121.4	2.05	133.7	2.10	147.1	2.15	160.9
.0012	1.93	92.5	1.99	103.4	2.04	114.7	2.09	126.8	2.14	139.6	2.20	153.7	2.24	167.7
.0013	2.01	96.3	2.07	107.7	2.12	119.5	2.17	132.0	2.23	145.3	2.29	160.0	2.34	174.9
.0014	2.08	99.9	2.15	111.7	2.20	124.0	2.26	137.0	2.31	150.8	2.37	166.0	2.42	181.5
.0015	2.16	103.4	2.22	115.6	2.28	128.3	2.34	141.8	2.39	156.1	2.45	171.8	2.51	187.9
.0016	2.23	106.9	2.29	119.4	2.35	132.5	2.41	146.5	2.47	161.2	2.53	177.4	2.59	194.0
.0017	2.29	110.1	2.36	123.1	2.43	136.6	2.49	151.0	2.55	166.2	2.61	182.8	2.67	200.0
.0018	2.36	113.3	2.43	126.7	2.50	140.5	2.56	155.3	2.62	171.0	2.69	188.2	2.75	205.8
.0019	2.43	116.4	2.50	130.2	2.56	144.4	2.63	159.6	2.69	175.7	2.76	193.3	2.82	211.5
.0020	2.49	119.4	2.56	133.5	2.63	148.1	2.70	163.7	2.76	180.2	2.83	198.3	2.90	216.9

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Exhibit 14-6 Ditch design tables
(Sheet 3 of 10)

Values of "V" and "Q" for Trapezoidal Ditches with 4-foot Bottom   Side Slopes 2:1   n = .040

Depth in Ft.	5.4		5.6		5.8		6.0		6.2		6.4		6.6	
X-Sec. Area	79.92		85.12		90.48		96.00		101.68		107.52		113.52	
Hyd. Radius	2.84		2.93		3.02		3.11		3.20		3.30		3.39	
S (Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.53	42.4	.54	46.0	.55	49.8	.56	53.8	.57	58.0	.58	62.4	.59	67.0
.00010	.75	59.9	.76	64.7	.78	70.6	.79	75.8	.81	82.4	.82	88.2	.84	95.4
.00015	.91	72.7	.93	79.2	.95	86.0	.97	93.1	.99	100.7	1.01	108.6	1.03	116.9
.00020	1.05	83.9	1.08	91.9	1.10	99.5	1.12	107.5	1.14	115.9	1.16	124.7	1.19	135.1
.00025	1.18	94.3	1.20	102.1	1.23	111.3	1.25	120.0	1.28	130.2	1.30	139.8	1.33	151.0
.00030	1.29	103.1	1.32	112.4	1.34	121.2	1.37	131.5	1.40	142.4	1.43	153.8	1.45	164.6
.00035	1.39	111.1	1.42	120.9	1.45	131.2	1.48	142.1	1.51	153.5	1.54	165.6	1.57	178.2
.00040	1.49	119.1	1.52	129.4	1.55	140.2	1.58	151.7	1.61	163.7	1.65	177.4	1.68	190.7
.00045	1.58	126.3	1.61	157.0	1.65	149.3	1.68	161.3	1.71	173.9	1.75	188.2	1.78	202.1
.00050	1.67	133.5	1.70	144.7	1.74	157.4	1.77	169.9	1.80	183.0	1.84	197.8	1.87	212.3
.00055	1.75	139.9	1.78	151.5	1.82	164.7	1.86	178.6	1.89	192.2	1.93	207.5	1.97	223.6
.00060	1.82	145.5	1.86	158.3	1.90	171.9	1.94	186.2	1.98	201.3	2.02	217.2	2.05	232.7
.00065	1.90	151.8	1.94	165.1	1.98	179.2	2.02	193.9	2.06	209.5	2.10	225.8	2.14	242.9
.00070	1.97	157.4	2.01	171.1	2.05	185.5	2.09	200.6	2.14	217.6	2.18	234.4	2.22	252.0
.00075	2.04	163.0	2.08	177.0	2.12	191.8	2.17	208.3	2.21	224.7	2.26	243.0	2.30	261.1
.00080	2.11	168.6	2.15	183.0	2.19	198.2	2.24	215.0	2.28	231.8	2.33	250.5	2.37	269.0
.00085	2.17	173.4	2.21	188.1	2.26	204.5	2.31	221.8	2.35	238.9	2.40	258.0	2.44	277.0
.00090	2.23	178.2	2.28	194.1	2.33	210.1	2.37	227.5	2.42	246.1	2.47	265.6	2.51	284.9
.00095	2.30	183.8	2.34	199.2	2.39	216.2	2.44	234.2	2.49	253.2	2.54	273.1	2.58	292.9
.00100	2.36	188.6	2.41	205.1	2.45	221.7	2.50	240.0	2.55	259.3	2.60	279.6	2.65	300.1
.0011	2.47	197.4	2.52	214.5	2.57	232.5	2.63	252.5	2.68	272.5	2.73	293.5	2.78	315.6
.0012	2.58	206.2	2.63	223.9	2.69	243.4	2.74	263.0	2.80	284.7	2.85	306.4	2.90	329.2
.0013	2.69	215.0	2.74	233.2	2.80	253.3	2.85	273.6	2.91	295.9	2.97	319.3	3.02	342.8
.0014	2.79	223.0	2.85	242.6	2.90	262.4	2.96	284.2	3.02	307.1	3.08	331.2	3.14	356.5
.0015	2.89	231.0	2.95	251.1	3.00	271.4	3.07	294.7	3.13	318.3	3.19	343.0	3.25	368.9
.0016	2.98	238.2	3.04	258.8	3.10	280.5	3.17	304.3	3.23	328.4	3.29	353.7	3.35	380.3
.0017	3.07	245.4	3.14	267.3	3.20	289.5	3.26	313.0	3.33	338.6	3.39	364.5	3.46	392.8
.0018	3.16	252.5	3.23	274.9	3.29	297.7	3.36	322.6	3.42	347.7	3.49	375.2	3.56	404.1
.0019	3.25	259.7	3.32	282.6	3.38	305.8	3.45	331.2	3.52	357.9	3.59	386.0	3.66	415.5
.0020	3.33	266.1	3.40	289.4	3.47	314.0	3.54	339.8	3.61	367.1	3.68	395.7	3.75	425.7

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Exhibit 14-6 Ditch design tables
(Sheet 4 of 10)

TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side Slopes and 6.0' Bottom - n = .045

Depth in Ft.	1.0		1.1		1.2		1.3		1.4		1.5		1.6	
X-Sect. Area	8.00		9.02		10.08		11.18		12.32		13.50		14.72	
Hyd. Radius	0.76		0.83		0.89		0.95		1.00		1.06		1.12	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.19	1.52	.20	1.80	.21	2.12	.22	2.46	.23	2.83	.24	3.24	.25	3.68
.00010	.27	2.16	.29	2.62	.30	3.02	.31	3.47	.33	4.07	.34	4.59	.35	5.15
.00015	.34	2.72	.36	3.25	.37	3.73	.38	4.25	.40	4.93	.42	5.67	.44	6.48
.00020	.38	3.04	.41	3.70	.43	4.33	.450	5.03	.47	5.79	.49	6.62	.50	7.36
.00025	.43	3.44	.46	4.15	.48	4.84	.500	5.59	.52	6.41	.54	7.29	.56	8.24
.00030	.47	3.76	.50	4.51	.53	5.34	.550	6.15	.57	7.02	.59	7.96	.62	9.13
.00035	.51	4.08	.54	4.81	.57	5.75	.595	6.65	.62	7.64	.64	8.64	.67	9.86
.00040	.55	4.40	.58	5.23	.61	6.15	.635	7.10	.66	8.13	.69	9.31	.71	10.45
.00045	.58	4.64	.62	5.59	.65	6.55	.675	7.55	.70	8.62	.73	9.85	.75	11.04
.00050	.62	4.96	.65	5.86	.68	6.85	.715	7.99	.74	9.12	.77	10.39	.80	11.77
.00055	.65	5.20	.68	6.22	.72	7.26	.745	8.33	.77	9.49	.81	10.93	.83	12.22
.00060	.68	5.44	.71	6.49	.75	7.56	.780	8.72	.81	9.98	.84	11.34	.87	12.81
.00065	.70	5.60	.75	6.76	.78	7.86	.810	9.06	.84	10.35	.88	11.88	.91	13.39
.00070	.72	5.76	.77	6.94	.81	8.16	.845	9.45	.87	10.72	.91	12.28	.94	13.84
.00075	.75	6.00	.80	7.22	.84	8.47	.870	9.73	.90	11.09	.94	12.69	.97	14.28
.00080	.77	6.16	.82	7.40	.86	8.67	.900	10.06	.93	11.46	.97	13.10	1.01	14.86
.00085	.80	6.40	.85	7.67	.89	8.97	.930	10.40	.96	11.83	1.00	13.50	1.04	15.30
.00090	.82	6.56	.87	7.85	.92	9.27	.955	10.68	.99	12.20	1.03	13.90	1.07	15.75
.00095	.85	6.80	.90	8.12	.94	9.48	.985	11.01	1.02	12.57	1.06	14.31	1.10	16.19
.0010	.87	6.96	.92	8.30	.97	9.78	1.005	11.24	1.04	12.81	1.09	14.71	1.12	16.49
.0011	.91	7.28	.97	8.75	1.01	10.18	1.055	11.79	1.10	13.55	1.14	15.39	1.18	17.37
.0012	.95	7.60	1.01	9.11	1.06	10.68	1.105	12.35	1.14	14.04	1.19	16.06	1.23	18.10
.0013	.99	7.92	1.05	9.47	1.10	11.09	1.150	12.86	1.19	14.66	1.24	16.74	1.28	18.84
.0014	1.03	8.24	1.09	9.83	1.14	11.49	1.190	13.30	1.24	15.27	1.29	17.41	1.33	19.58
.0015	1.06	8.48	1.13	10.19	1.18	11.89	1.235	13.81	1.28	15.77	1.33	17.96	1.38	20.31
.0016	1.10	8.80	1.17	10.55	1.22	12.30	1.275	14.25	1.32	16.26	1.37	18.50	1.43	21.05
.0017	1.13	9.04	1.20	10.82	1.26	12.70	1.315	14.71	1.36	16.75	1.42	19.17	1.47	21.64
.0018	1.17	9.36	1.24	11.18	1.30	13.10	1.350	15.09	1.40	17.25	1.46	19.71	1.51	22.23
.0019	1.20	9.60	1.27	11.85	1.33	13.41	1.390	15.54	1.44	17.74	1.50	20.25	1.55	22.82
.0020	1.23	9.84	1.30	11.73	1.37	13.81	1.425	15.93	1.48	18.23	1.54	20.79	1.59	23.40
.0021	1.26	10.08	1.34	12.09	1.40	14.11	1.460	16.32	1.51	18.60	1.57	21.19	1.63	23.99
.0022	1.29	10.32	1.37	12.36	1.43	14.41	1.495	16.71	1.55	19.10	1.61	21.73	1.67	24.58
.0023	1.32	10.56	1.40	12.63	1.46	14.72	1.530	17.10	1.58	19.47	1.65	22.27	1.71	25.19
.0024	1.34	10.72	1.43	12.90	1.50	15.12	1.565	17.50	1.62	19.96	1.68	22.68	1.74	25.61
.0025	1.37	10.96	1.46	13.17	1.53	15.42	1.595	17.83	1.65	20.33	1.72	23.32	1.78	26.20

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Exhibit 14-6 Ditch design tables
(Sheet 5 of 10)

TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side Slopes and 6.0' Bottom - n = .045

Depth in Ft.	1.7		1.8		1.9		2.0		2.1		2.2		2.3	
X-Sect. Area	15.98		17.28		18.62		20.00		21.42		22.88		24.38	
Hyd. Radius	1.17		1.23		1.28		1.34		1.39		1.44		1.49	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.25	4.00	.26	4.49	.27	5.03	.28	5.60	.29	6.21	.29	6.64	.30	7.31
.00010	.36	5.75	.38	6.57	.39	7.26	.40	8.00	.41	8.78	.42	9.61	.43	10.48
.00015	.45	7.19	.47	8.12	.48	8.94	.49	9.80	.51	10.92	.52	11.90	.53	12.92
.00020	.518	8.28	.536	9.26	.546	10.17	.567	11.34	.581	12.44	.592	13.54	.607	14.80
.00025	.579	9.25	.599	10.35	.614	11.43	.632	12.64	.647	13.86	.662	15.15	.677	16.50
.00030	.635	10.15	.659	11.39	.674	12.55	.696	13.92	.716	15.34	.732	16.75	.747	18.21
.00035	.686	10.96	.709	12.25	.724	13.48	.746	14.92	.766	16.41	.786	17.98	.806	19.65
.00040	.733	11.71	.762	13.17	.782	14.56	.806	16.12	.826	17.69	.842	19.26	.857	20.89
.00045	.777	12.41	.802	13.86	.822	15.31	.85	17.00	.875	18.74	.896	20.50	.916	22.33
.00050	.819	13.08	.842	14.55	.862	16.05	.897	17.94	.915	19.60	.941	21.53	.963	23.48
.00055	.859	13.73	.885	15.29	.910	16.94	.94	18.80	.965	20.67	.986	22.56	1.006	24.53
.00060	.897	14.33	.925	15.98	.95	17.69	.98	19.60	1.005	21.53	1.030	23.57	1.055	25.72
.00065	.934	14.92	.965	16.67	.99	18.43	1.02	20.40	1.045	22.38	1.070	24.48	1.095	26.70
.00070	.969	15.48	1.005	17.37	1.03	19.18	1.06	21.20	1.085	23.24	1.110	25.40	1.135	27.67
.00075	1.003	16.03	1.035	17.88	1.06	19.74	1.094	21.88	1.124	24.08	1.150	26.31	1.175	28.65
.00080	1.036	16.55	1.068	18.45	1.098	20.44	1.134	22.68	1.164	24.93	1.190	27.23	1.215	29.62
.00085	1.068	17.06	1.105	19.09	1.13	21.04	1.164	23.28	1.194	25.57	1.224	28.01	1.254	30.57
.00090	1.099	17.56	1.138	19.66	1.168	21.75	1.204	24.08	1.234	26.43	1.264	28.92	1.294	31.55
.00095	1.129	18.04	1.168	20.18	1.198	22.31	1.234	24.68	1.264	27.07	1.294	29.61	1.324	32.23
.0010	1.159	18.52	1.198	20.70	1.228	22.86	1.268	25.36	1.303	27.91	1.334	30.52	1.364	33.25
.0011	1.216	19.43	1.258	21.74	1.288	23.98	1.328	26.56	1.363	29.20	1.394	31.89	1.424	34.72
.0012	1.269	20.28	1.311	22.65	1.346	25.06	1.384	27.68	1.423	30.48	1.458	33.36	1.493	36.40
.0013	1.319	21.08	1.364	23.57	1.404	26.14	1.448	28.96	1.483	31.77	1.518	34.73	1.553	37.86
.0014	1.371	21.91	1.414	24.43	1.454	27.07	1.502	30.04	1.542	33.03	1.578	36.10	1.613	39.33
.0015	1.419	22.68	1.464	25.30	1.504	28.00	1.552	31.04	1.592	34.10	1.628	37.25	1.663	40.54
.0016	1.466	23.43	1.514	26.16	1.554	28.94	1.602	32.04	1.642	35.17	1.682	38.48	1.722	41.98
.0017	1.511	24.14	1.564	27.02	1.604	29.87	1.652	33.04	1.692	36.24	1.732	39.63	1.772	43.20
.0018	1.555	24.85	1.607	27.77	1.652	30.76	1.702	34.04	1.742	37.31	1.782	40.77	1.822	44.42
.0019	1.60	25.57	1.654	28.58	1.694	31.54	1.746	34.92	1.791	38.36	1.836	42.01	1.881	45.86
.0020	1.64	26.21	1.697	29.32	1.742	32.43	1.796	35.92	1.841	39.43	1.882	43.06	1.922	46.86
.0021	1.68	26.85	1.737	30.01	1.782	33.18	1.836	36.72	1.881	40.29	1.926	44.07	1.971	48.05
.0022	1.72	27.49	1.777	30.70	1.822	33.93	1.88	37.60	1.930	41.34	1.976	45.21	2.021	49.27
.0023	1.76	28.12	1.82	31.45	1.870	34.82	1.926	38.52	1.971	42.22	2.016	46.13	2.061	50.25
.0024	1.795	28.68	1.86	32.14	1.910	35.56	1.966	39.32	2.011	43.08	2.060	47.13	2.110	51.44
.0025	1.83	29.24	1.893	32.71	1.948	36.27	2.01	40.20	2.060	44.12	2.106	48.19	2.151	52.44

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Exhibit 14-6 Ditch design tables
(Sheet 6 of 10)

TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side Slopes and 6.0' Bottom - n = .045

Depth in Ft.	2.4		2.5		2.6		2.7		2.8		2.9		3.0	
X-Sec. Area	25.92		27.50		29.12		30.78		32.48		34.22		36.00	
Hyd. Radius	1.55		1.60		1.65		1.70		1.75		1.80		1.85	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.31	8.04	.32	8.80	.325	9.46	.33	10.16	.34	11.04	.35	11.98	.355	12.78
.00010	.44	11.40	.45	12.37	.46	13.39	.47	14.47	.48	15.59	.49	16.77	.495	17.82
.00015	.54	14.00	.55	15.12	.56	16.31	.57	17.54	.58	18.84	.60	20.53	.61	21.96
.00020	.62	16.07	.64	17.60	.65	18.93	.66	20.31	.67	21.76	.69	23.61	.70	25.20
.00025	.69	17.88	.71	19.52	.72	20.97	.74	22.78	.75	24.36	.77	26.35	.78	28.08
.00030	.76	19.70	.78	21.45	.79	23.00	.81	24.93	.83	26.96	.85	29.09	.86	30.96
.00035	.83	21.51	.85	23.37	.86	25.04	.88	27.09	.89	28.91	.91	31.14	.92	33.12
.00040	.88	22.81	.90	24.75	.92	26.79	.94	28.93	.96	31.18	.98	33.54	.99	35.64
.00045	.94	24.36	.96	26.40	.98	28.54	1.00	30.78	1.02	33.13	1.04	35.59	1.05	37.80
.00050	.98	25.40	1.01	27.77	1.03	29.99	1.05	32.32	1.07	34.75	1.09	37.30	1.11	39.96
.00055	1.03	26.70	1.06	29.15	1.08	31.45	1.10	33.86	1.12	36.38	1.15	39.35	1.17	42.12
.00060	1.08	27.99	1.11	30.52	1.13	32.91	1.15	35.40	1.17	38.00	1.20	41.06	1.22	43.92
.00065	1.12	29.03	1.15	31.62	1.17	34.07	1.20	36.94	1.22	39.63	1.25	42.77	1.27	45.72
.00070	1.15	29.81	1.20	33.00	1.22	35.53	1.24	38.17	1.26	40.92	1.29	44.14	1.31	47.16
.00075	1.21	31.36	1.24	34.10	1.26	36.69	1.29	39.71	1.31	42.55	1.34	45.85	1.36	48.96
.00080	1.25	32.40	1.28	35.20	1.30	37.86	1.33	40.94	1.35	43.85	1.38	47.22	1.40	50.40
.00085	1.29	33.44	1.32	36.30	1.34	39.02	1.37	42.17	1.39	45.15	1.42	48.59	1.44	51.84
.00090	1.33	34.47	1.36	37.40	1.38	40.18	1.41	43.40	1.44	46.77	1.47	50.30	1.49	53.64
.00095	1.36	35.25	1.39	38.22	1.42	46.35	1.45	44.63	1.48	48.07	1.51	51.67	1.53	55.08
.0010	1.40	36.29	1.43	39.32	1.46	42.51	1.49	45.86	1.52	49.37	1.55	53.04	1.57	56.52
.0011	1.46	37.84	1.50	41.25	1.53	44.56	1.56	48.02	1.59	51.64	1.62	55.44	1.65	59.40
.0012	1.53	39.66	1.56	42.90	1.59	46.30	1.63	50.17	1.66	53.92	1.69	57.83	1.72	61.92
.0013	1.59	41.21	1.63	44.82	1.66	48.34	1.69	52.02	1.72	55.87	1.76	60.23	1.79	64.44
.0014	1.66	43.03	1.69	46.47	1.72	50.09	1.76	54.17	1.79	58.14	1.83	62.62	1.86	66.96
.0015	1.71	44.32	1.75	48.12	1.78	51.83	1.82	56.02	1.85	60.09	1.89	64.68	1.92	69.12
.0016	1.76	45.62	1.80	49.50	1.84	53.58	1.88	57.87	1.91	62.04	1.95	66.73	1.99	71.64
.0017	1.82	47.43	1.86	51.15	1.90	55.33	1.94	59.71	1.97	63.99	2.01	68.78	2.05	73.80
.0018	1.86	48.21	1.91	52.52	1.95	56.78	1.99	61.25	2.03	65.93	2.07	70.84	2.11	75.96
.0019	1.93	50.03	1.97	54.17	2.01	58.53	2.05	63.10	2.09	67.88	2.13	72.89	2.15	77.40
.0020	1.97	51.06	2.02	55.55	2.06	59.99	2.10	64.64	2.14	69.51	2.19	74.94	2.23	80.28

Exhibit 14-6 Ditch design tables
(Sheet 7 of 10)

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TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side Slopes and 6.0' Bottom - n = .045

Depth in Ft.	3.1		3.2		3.3		3.4		3.5		3.6		3.7		3.8	
X-Sec. Area	37.82		39.68		41.58		43.52		45.50		47.52		49.58		51.68	
Hyd. Radius	1.90		1.95		2.00		2.05		2.10		2.15		2.19		2.25	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.36	13.61	.365	14.48	.37	15.38	.375	16.32	.38	17.29	.385	18.30	.39	19.34	.39	20.16
.00010	.50	18.91	.51	20.24	.52	21.62	.53	23.06	.54	24.57	.55	26.14	.56	27.76	.56	28.94
.00015	.62	23.45	.63	25.00	.64	26.61	.65	28.29	.66	30.03	.67	31.84	.68	33.71	.69	35.66
.00020	.71	26.85	.725	28.77	.74	30.77	.75	32.64	.76	34.58	.77	36.59	.79	39.17	.80	41.34
.00025	.80	30.26	.815	32.34	.83	34.51	.84	36.56	.85	38.67	.86	40.87	.88	43.63	.89	46.00
.00030	.88	33.28	.895	35.51	.91	37.84	.92	40.04	.94	42.77	.95	45.14	.97	48.09	.98	50.65
.00035	.94	35.55	.96	38.09	.98	40.75	.99	43.08	1.01	45.95	1.03	48.95	1.05	52.06	1.06	54.78
.00040	1.01	38.20	1.03	40.87	1.05	43.66	1.06	46.13	1.08	49.14	1.10	52.27	1.12	55.53	1.13	58.40
.00045	1.07	40.47	1.09	43.25	1.11	46.15	1.12	48.74	1.14	51.87	1.16	55.12	1.18	58.50	1.20	62.02
.00050	1.13	42.74	1.15	45.63	1.17	48.65	1.19	51.79	1.21	55.05	1.23	58.45	1.25	61.48	1.26	65.12
.00055	1.19	45.01	1.21	48.01	1.23	51.14	1.25	54.40	1.27	57.78	1.29	61.30	1.31	64.45	1.33	68.73
.00060	1.24	46.90	1.26	50.00	1.28	53.22	1.30	56.58	1.32	60.06	1.34	63.68	1.36	67.43	1.39	71.84
.00065	1.29	48.79	1.31	51.98	1.34	55.72	1.36	59.19	1.38	62.79	1.40	66.53	1.41	69.91	1.44	74.42
.00070	1.34	50.68	1.36	53.96	1.39	57.80	1.41	61.36	1.43	65.06	1.45	68.90	1.47	72.88	1.50	77.52
.00075	1.39	52.57	1.41	55.95	1.44	59.88	1.46	63.54	1.48	67.34	1.50	71.28	1.52	75.36	1.55	80.10
.00080	1.43	54.08	1.45	57.54	1.48	61.54	1.50	65.28	1.53	69.61	1.55	73.66	1.57	77.84	1.60	82.69
.00085	1.47	55.60	1.50	59.52	1.53	63.62	1.55	67.46	1.58	71.89	1.60	76.03	1.62	80.32	1.65	85.27
.00090	1.52	57.49	1.54	61.11	1.57	65.28	1.59	69.20	1.62	73.71	1.65	78.41	1.67	82.80	1.70	87.86
.00095	1.56	59.00	1.59	63.09	1.62	67.36	1.64	71.37	1.67	75.98	1.69	80.31	1.71	84.78	1.74	89.92
.00100	1.60	60.51	1.63	64.68	1.66	69.02	1.68	73.11	1.71	77.80	1.74	82.68	1.76	87.26	1.79	92.51
.0011	1.68	63.54	1.71	67.85	1.74	72.35	1.76	76.60	1.79	81.44	1.82	86.49	1.84	91.23	1.87	96.64
.0012	1.75	66.18	1.78	70.63	1.82	75.68	1.85	80.52	1.88	85.54	1.90	90.29	1.92	95.19	1.95	100.78
.0013	1.83	69.21	1.86	73.80	1.89	78.59	1.92	83.56	1.95	88.72	1.98	94.09	2.00	99.16	2.03	104.91
.0014	1.89	71.48	1.92	76.19	1.96	81.50	1.99	86.60	2.03	92.36	2.06	97.89	2.08	103.13	2.11	109.04
.0015	1.96	74.13	1.99	78.96	2.03	84.41	2.06	89.65	2.09	95.09	2.12	100.74	2.15	106.60	2.18	112.66
.0016	2.03	76.77	2.06	81.74	2.10	87.32	2.13	92.70	2.17	98.73	2.20	105.54	2.22	110.07	2.26	116.80
.0017	2.09	79.04	2.12	84.12	2.16	89.81	2.19	95.31	2.23	101.46	2.26	107.40	2.29	113.54	2.33	120.41
.0018	2.15	81.31	2.18	86.50	2.22	92.31	2.26	98.36	2.30	104.65	2.33	110.72	2.36	117.01	2.40	124.03
.0019	2.21	83.58	2.24	88.88	2.28	94.80	2.32	100.97	2.36	107.38	2.39	113.57	2.42	119.98	2.46	127.13
.0020	2.27	85.85	2.30	91.26	2.34	97.30	2.37	103.14	2.42	110.11	2.46	116.90	2.49	123.45	2.53	130.75

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Exhibit 14-6 Ditch design tables
(Sheet 8 of 10)

TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side Slopes and 6.0' Bottom

	n = .045										n = .040					
Depth in Ft.	3.9		4.0		4.1		4.2		4.3		4.4		4.5		4.6	
X-Sec. Area	53.82		56.00		58.22		60.48		62.78		65.12		67.50		69.92	
Hyd. Radius	2.29		2.34		2.39		2.44		2.49		2.53		2.58		2.63	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.40	21.53	.41	22.96	.42	24.45	.42	25.40	.43	27.00	.49	31.91	.50	33.75	.50	34.96
.00010	.57	30.68	.58	32.48	.59	34.35	.59	35.68	.60	37.67	.69	44.93	.70	47.25	.71	49.64
.00015	.70	37.67	.71	39.76	.72	41.92	.73	44.15	.74	46.46	.85	55.35	.86	58.05	.87	60.83
.00020	.81	43.59	.82	45.92	.84	48.90	.85	51.41	.86	53.99	.97	63.17	.98	66.15	1.00	69.92
.00025	.91	48.98	.92	51.52	.94	54.73	.95	57.46	.96	60.27	1.09	70.98	1.10	74.25	1.12	78.31
.00030	1.00	53.82	1.01	56.56	1.03	59.97	1.04	62.90	1.05	65.92	1.19	77.49	1.21	81.67	1.23	86.00
.00035	1.08	58.13	1.09	61.04	1.11	64.62	1.12	67.74	1.14	71.57	1.29	84.00	1.30	87.75	1.32	92.29
.00040	1.15	61.89	1.16	64.96	1.18	68.70	1.19	71.97	1.21	75.96	1.37	89.21	1.39	93.82	1.41	98.59
.00045	1.22	65.66	1.24	69.44	1.26	73.36	1.27	76.81	1.29	80.99	1.46	95.08	1.48	99.90	1.50	104.88
.00050	1.28	68.89	1.30	72.80	1.32	76.85	1.34	80.44	1.36	85.38	1.54	100.28	1.56	105.30	1.58	110.47
.00055	1.35	72.66	1.37	76.72	1.39	80.93	1.40	84.67	1.42	89.15	1.62	105.49	1.64	110.70	1.66	116.08
.00060	1.41	75.89	1.43	80.08	1.45	84.42	1.47	88.91	1.49	93.54	1.69	110.05	1.71	115.42	1.74	121.66
.00065	1.46	78.58	1.48	82.88	1.51	87.91	1.53	92.53	1.55	97.31	1.76	114.61	1.78	120.15	1.80	125.86
.00070	1.52	81.81	1.54	86.24	1.57	91.41	1.59	96.16	1.61	101.08	1.83	119.17	1.85	124.87	1.87	130.75
.00075	1.57	84.50	1.59	89.04	1.62	94.32	1.64	99.19	1.66	104.21	1.89	123.08	1.91	128.92	1.94	135.64
.00080	1.62	87.19	1.64	91.84	1.67	97.23	1.69	102.21	1.72	107.98	1.95	126.98	1.97	132.97	2.01	140.54
.00085	1.68	90.42	1.70	95.20	1.73	100.72	1.75	105.84	1.77	111.12	2.01	130.89	2.04	137.70	2.07	144.73
.00090	1.73	93.11	1.75	98.00	1.78	103.63	1.80	108.86	1.82	114.26	2.07	134.80	2.10	141.75	2.13	148.93
.00095	1.77	95.26	1.79	100.24	1.82	105.96	1.84	111.28	1.87	117.40	2.13	138.71	2.16	145.80	2.19	153.12
.00100	1.82	97.95	1.84	103.04	1.87	108.87	1.89	114.31	1.92	120.54	2.18	141.96	2.21	149.17	2.24	156.62
.0011	1.90	102.26	1.93	108.08	1.96	114.11	1.98	119.75	2.01	126.19	2.29	149.12	2.32	156.60	2.35	164.31
.0012	1.98	106.56	2.01	112.56	2.04	118.77	2.07	125.19	2.10	131.84	2.39	155.64	2.42	163.35	2.45	171.30
.0013	2.06	110.87	2.09	117.04	2.12	123.43	2.15	130.03	2.18	136.86	2.49	162.15	2.52	170.10	2.55	178.30
.0014	2.14	115.17	2.17	121.52	2.20	128.08	2.23	134.87	2.26	141.88	2.58	168.01	2.62	176.85	2.65	185.29
.0015	2.21	118.94	2.25	126.00	2.28	132.74	2.31	139.71	2.34	146.91	2.67	173.87	2.71	182.92	2.74	191.58
.0016	2.29	123.25	2.33	130.48	2.36	137.40	2.39	144.55	2.42	151.93	2.76	179.73	2.80	189.00	2.83	197.87
.0017	2.36	127.02	2.40	134.40	2.43	141.47	2.47	149.39	2.50	156.95	2.85	185.59	2.89	195.07	2.93	204.87
.0018	2.43	130.78	2.47	138.32	2.50	145.55	2.54	153.62	2.57	161.34	2.92	190.15	2.96	199.80	3.00	209.76
.0019	2.50	134.55	2.54	142.24	2.57	149.63	2.61	157.85	2.64	165.74	3.00	195.36	3.04	205.20	3.08	215.35
.0020	2.56	137.78	2.60	145.60	2.64	153.70	2.68	162.09	2.71	170.13	3.08	200.57	3.12	210.60	3.16	220.95

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Exhibit 14-6 Ditch design tables
(Sheet 9 of 10)

TABLE OF VALUES OF "V" AND "Q" FOR TRAPEZOIDAL DITCHES with 2:1 Side slopes and 6.0' Bottom - n = .040

Depth in Ft.	4.7		4.8		4.9		5.0		5.1		5.2		5.3		5.4	
X-Sec. Area	72.38		74.88		77.42		80.00		82.62		85.28		87.98		90.72	
Hyd. Radius	2.68		2.72		2.77		2.82		2.87		2.91		2.96		3.01	
S-(Ft./Ft.)	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
.00005	.51	36.91	.51	38.19	.52	40.26	.52	41.60	.53	43.79	.54	46.05	.54	47.50	.55	49.90
.00010	.72	52.11	.72	53.91	.73	56.52	.74	59.20	.75	61.96	.76	64.81	.77	67.74	.77	69.85
.00015	.88	63.69	.88	65.89	.89	68.90	.91	72.80	.92	76.01	.93	79.31	.94	82.70	.95	86.18
.00020	1.01	73.10	1.02	76.38	1.03	79.74	1.04	83.20	1.05	86.75	1.06	90.40	1.08	95.02	1.09	98.88
.00025	1.13	81.79	1.15	86.11	1.16	89.81	1.17	93.60	1.18	97.49	1.19	101.48	1.21	106.46	1.22	110.68
.00030	1.24	89.75	1.26	94.35	1.27	98.32	1.29	103.20	1.30	107.41	1.31	111.72	1.33	117.01	1.34	121.56
.00035	1.33	96.27	1.35	101.09	1.37	106.07	1.39	111.20	1.40	115.67	1.41	120.24	1.43	125.81	1.45	131.54
.00040	1.43	103.50	1.45	108.58	1.47	113.81	1.49	119.20	1.50	123.93	1.51	128.77	1.53	134.61	1.55	140.62
.00045	1.52	110.02	1.54	115.32	1.56	120.78	1.58	126.40	1.59	131.37	1.60	136.45	1.62	142.53	1.64	148.78
.00050	1.60	115.81	1.62	121.31	1.64	126.97	1.66	132.80	1.68	138.80	1.69	144.12	1.71	150.45	1.73	156.95
.00055	1.68	121.60	1.70	127.30	1.72	133.16	1.74	139.20	1.76	145.41	1.77	150.95	1.79	157.48	1.81	164.20
.00060	1.76	127.39	1.78	133.29	1.80	139.36	1.82	145.60	1.84	152.02	1.85	157.77	1.87	164.52	1.90	172.37
.00065	1.82	131.73	1.84	137.78	1.87	144.78	1.89	151.20	1.91	157.80	1.93	164.59	1.95	171.56	1.97	178.72
.00070	1.89	136.80	1.91	143.02	1.94	150.19	1.96	156.80	1.98	163.59	2.00	170.56	2.02	177.72	2.04	185.07
.00075	1.96	141.86	1.98	148.26	2.01	155.61	2.03	162.40	2.06	170.20	2.08	177.38	2.10	184.76	2.12	192.33
.00080	2.03	146.93	2.05	153.50	2.08	161.03	2.10	168.00	2.13	175.98	2.15	183.35	2.17	190.92	2.19	198.68
.00085	2.09	151.27	2.11	158.00	2.14	165.68	2.16	172.80	2.19	180.94	2.21	188.47	2.23	196.20	2.26	205.03
.00090	2.15	155.62	2.17	162.49	2.20	170.32	2.22	177.60	2.25	185.89	2.27	193.59	2.30	202.35	2.33	211.38
.00095	2.21	159.96	2.23	166.98	2.26	174.97	2.28	182.40	2.31	190.85	2.33	198.70	2.36	207.63	2.39	216.82
.00100	2.26	163.58	2.28	170.73	2.32	179.61	2.34	187.20	2.37	195.81	2.39	203.82	2.42	212.91	2.45	222.26
.0011	2.38	172.26	2.40	179.71	2.43	188.13	2.46	196.80	2.49	205.72	2.52	214.91	2.54	223.47	2.57	233.15
.0012	2.49	180.23	2.51	187.95	2.54	196.65	2.57	205.60	2.60	214.81	2.63	224.29	2.66	234.03	2.69	244.04
.0013	2.59	187.46	2.61	195.44	2.64	204.39	2.67	213.60	2.70	223.07	2.73	232.81	2.76	242.82	2.80	254.02
.0014	2.69	194.70	2.71	202.92	2.74	212.13	2.77	221.60	2.81	232.16	2.84	242.20	2.86	251.62	2.90	263.09
.0015	2.78	201.22	2.80	209.66	2.84	219.87	2.87	229.60	2.91	240.42	2.94	250.72	2.96	260.42	3.00	272.16
.0016	2.87	207.73	2.89	216.40	2.93	226.84	2.96	236.80	3.00	247.86	3.03	258.40	3.06	269.22	3.10	281.23
.0017	2.97	214.97	2.99	223.89	3.03	234.58	3.07	245.60	3.11	256.95	3.14	267.78	3.17	278.90	3.21	291.21
.0018	3.04	220.04	3.07	229.88	3.11	240.78	3.15	252.00	3.19	263.56	3.22	274.60	3.25	285.93	3.29	298.47
.0019	3.12	225.83	3.16	236.62	3.20	247.74	3.23	258.40	3.27	270.17	3.30	281.42	3.34	293.85	3.38	306.63
.0020	3.20	231.62	3.24	242.61	3.28	253.94	3.32	265.60	3.36	277.60	3.39	289.10	3.43	301.77	3.47	314.80

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Exhibit 14-6 Ditch design tables
(Sheet 10 of 10)

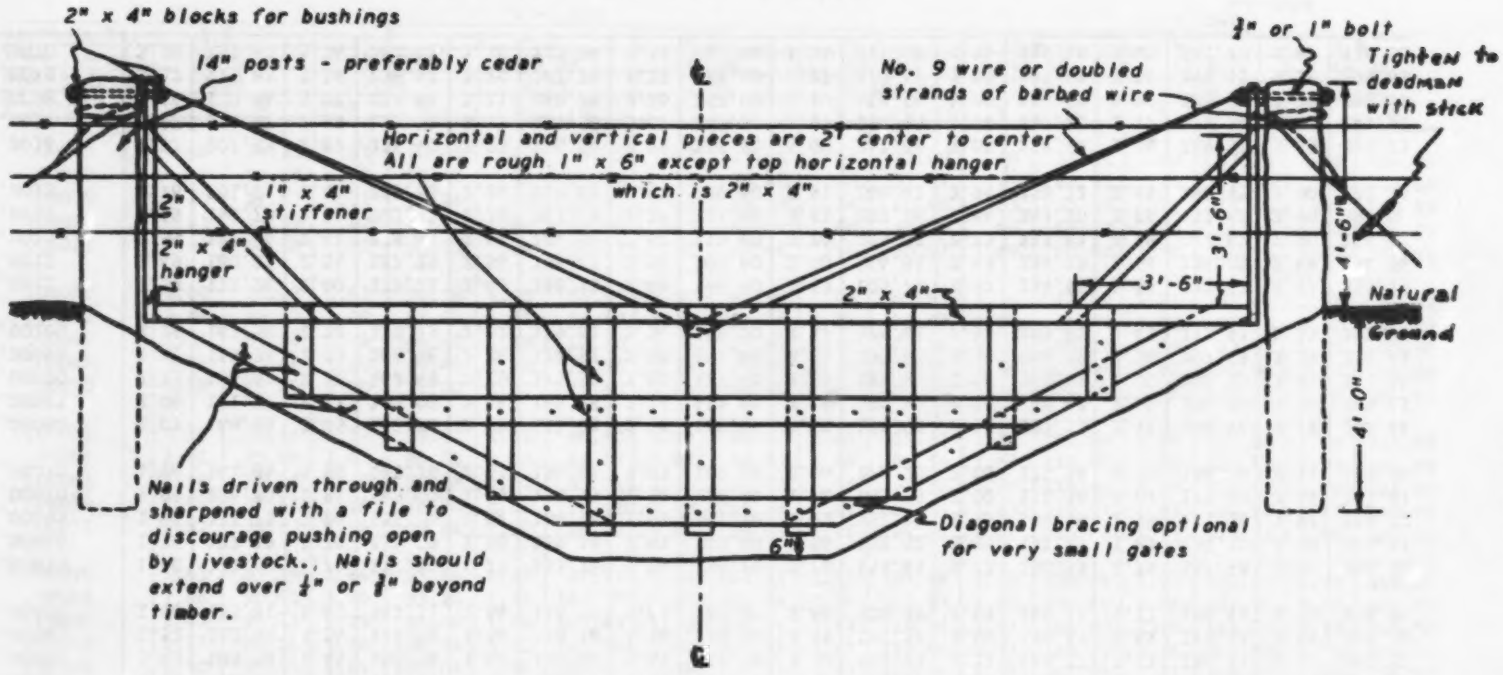

2" x 4" blocks for bushings
14" posts - preferably cedar
No. 9 wire or doubled strands of barbed wire
¾" or 1" bolt
Tighten to deadman with stick
Horizontal and vertical pieces are 2' center to center
All are rough 1" x 6" except top horizontal hanger which is 2" x 4"
1" x 4" stiffener
2"
2" x 4" hanger
2" x 4"
3'-6"
3'-6"
4'-6"
4'-0"
Natural Ground
℄
℄
6"
Nails driven through and sharpened with a file to discourage pushing open by livestock. Nails should extend over ¼" or ⅜" beyond timber.
Diagonal bracing optional for very small gates

Exhibit 14-7 Typical plan of a swinging watergate

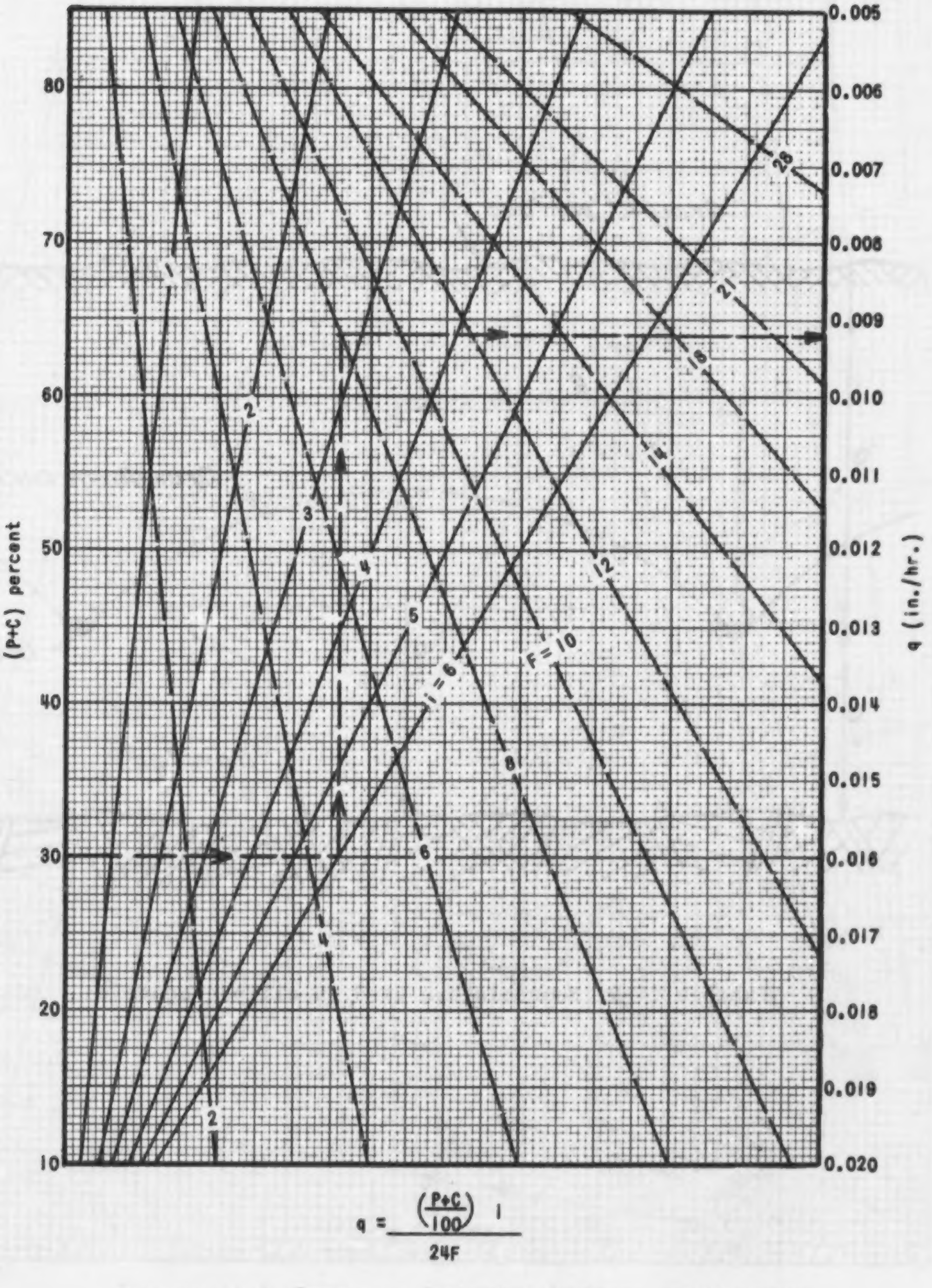


Exhibit 14-8 Curves to determine drainage coefficients

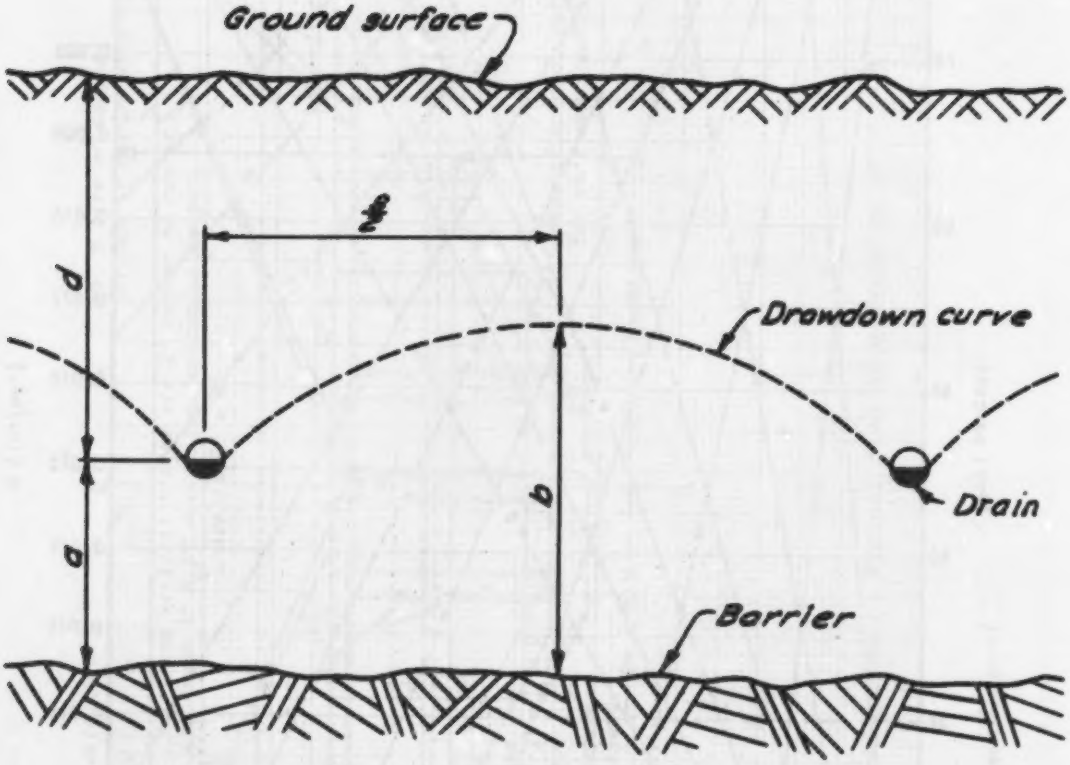

Ground surface
℄
d
Drawdown curve
a
b
Drain
Barrier

Exhibit 14-9 Nomenclature used in ellipse equation

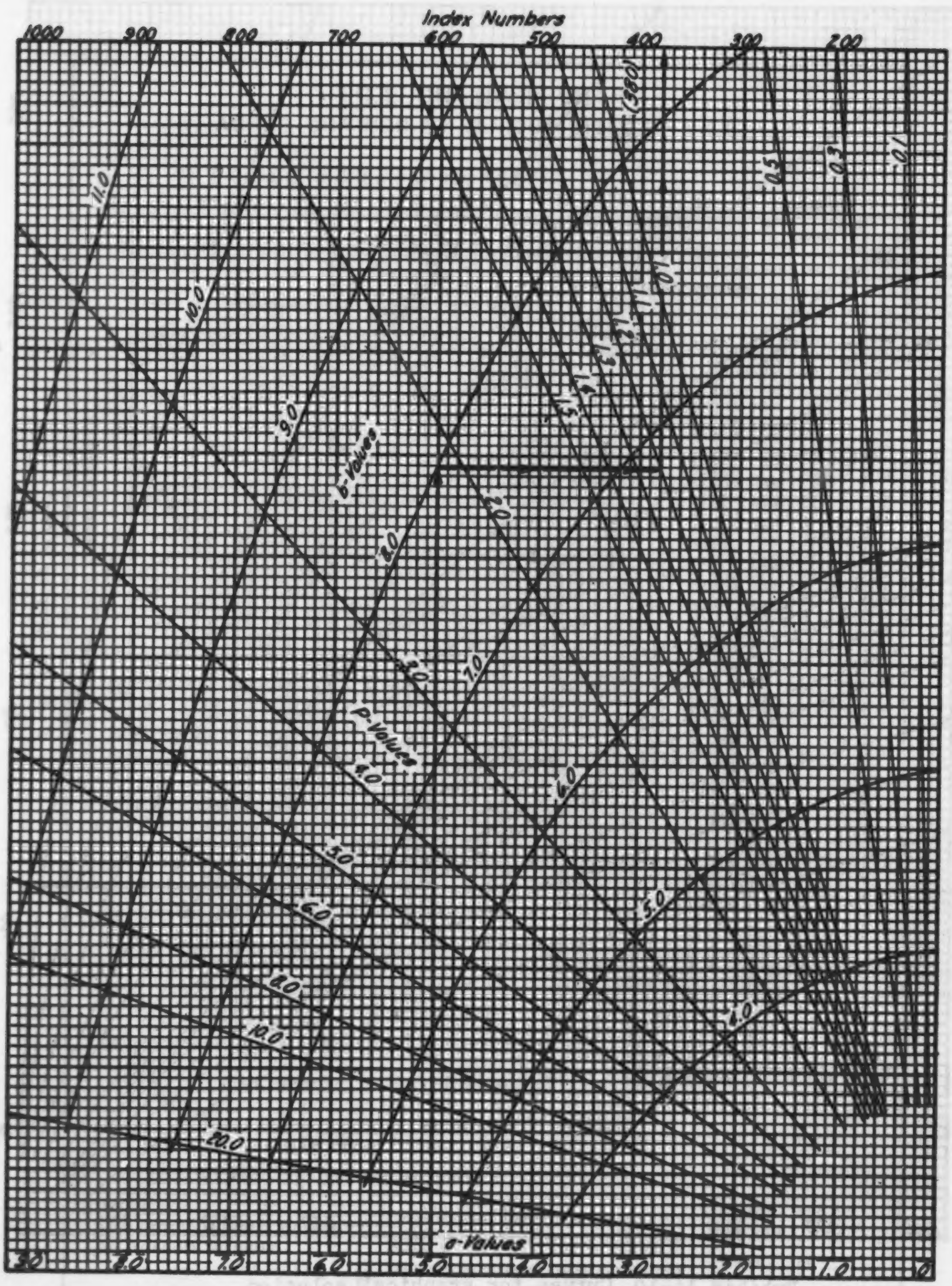


Exhibit 14-10 Curves for graphical solution of ellipse formula (Sheet 1 of 2)

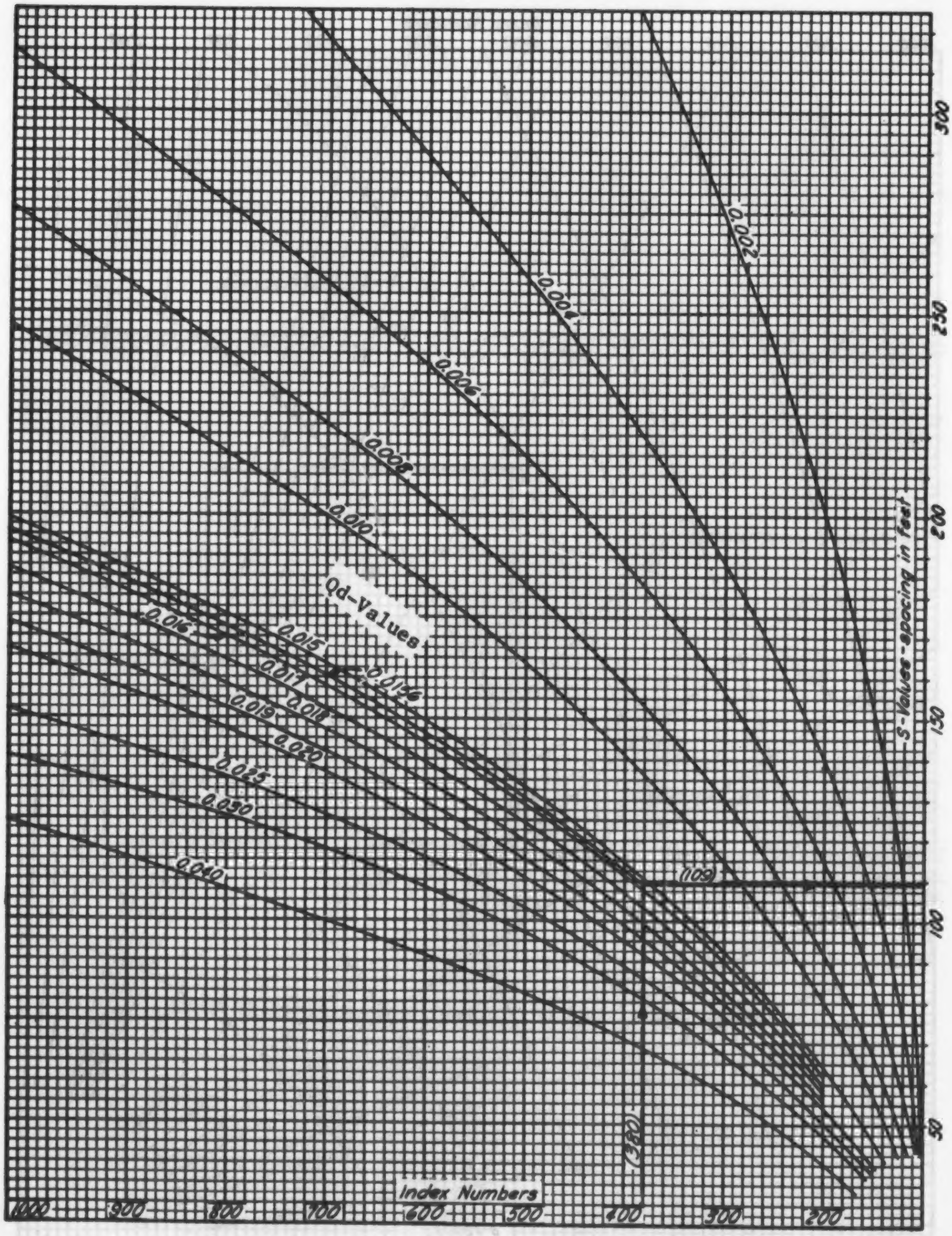


Exhibit 14-10 Curves for graphical solution of ellipse formula (Sheet 2 of 2)

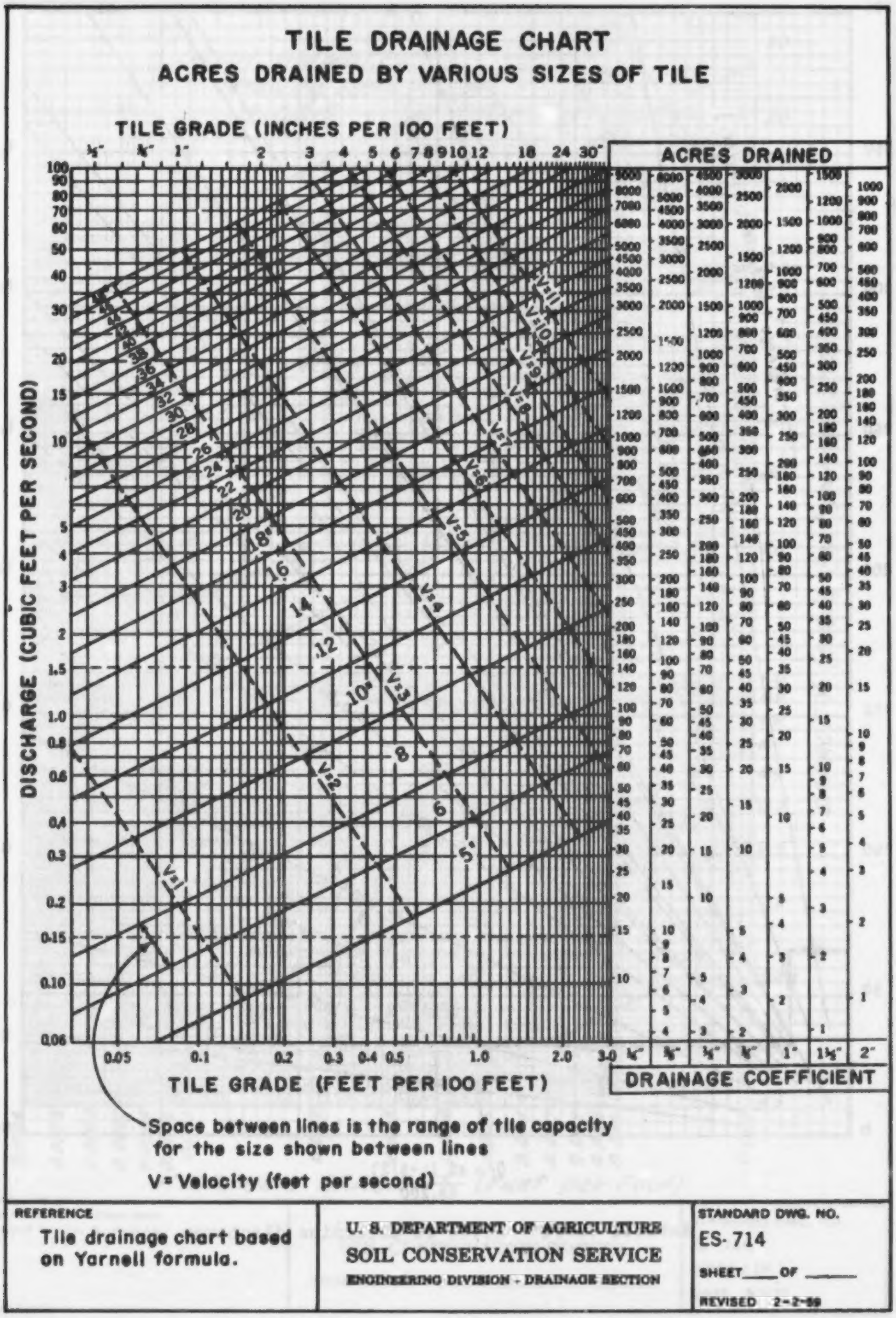


Exhibit 14-11 Chart for determining required size of clay or concrete draintile

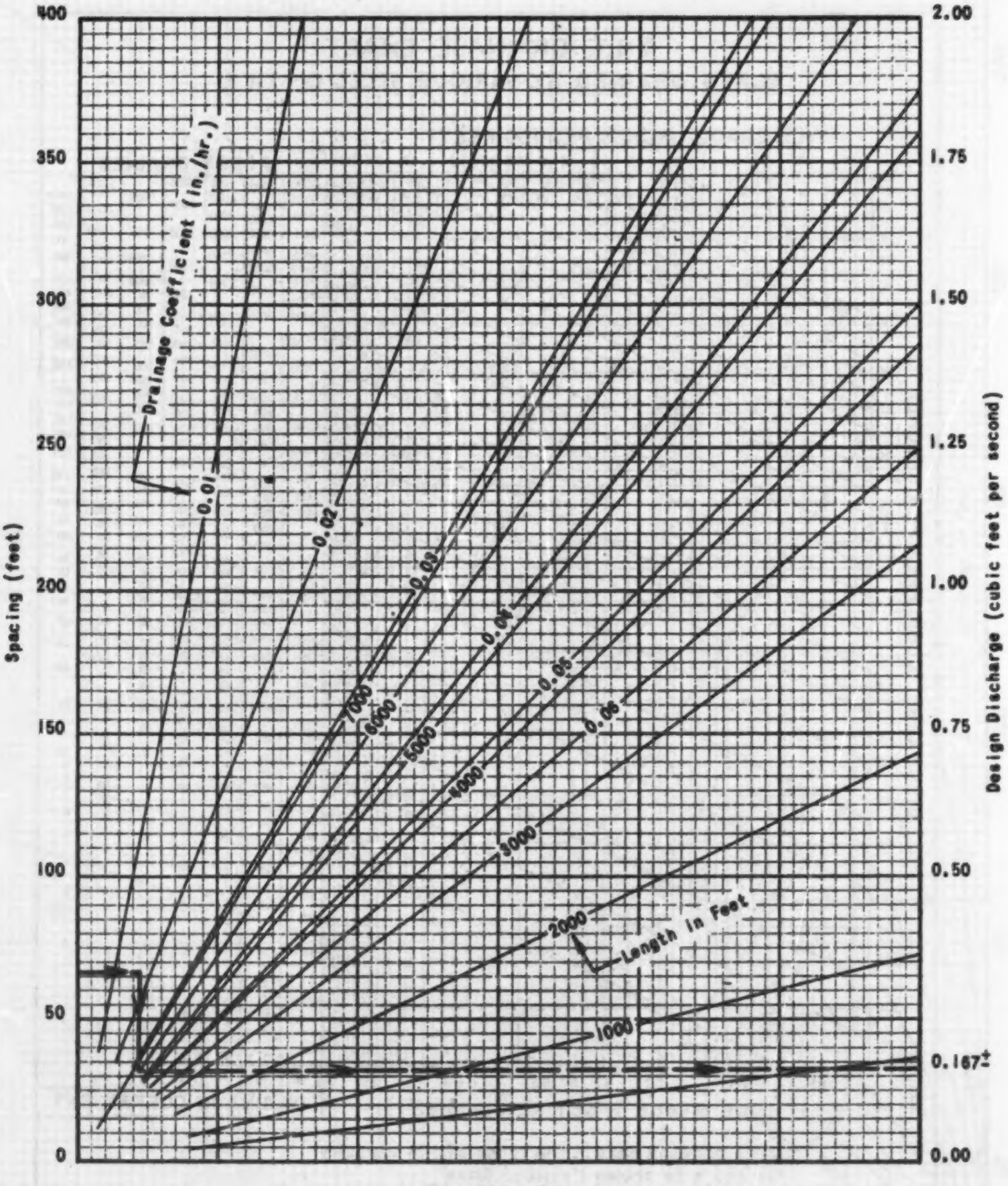
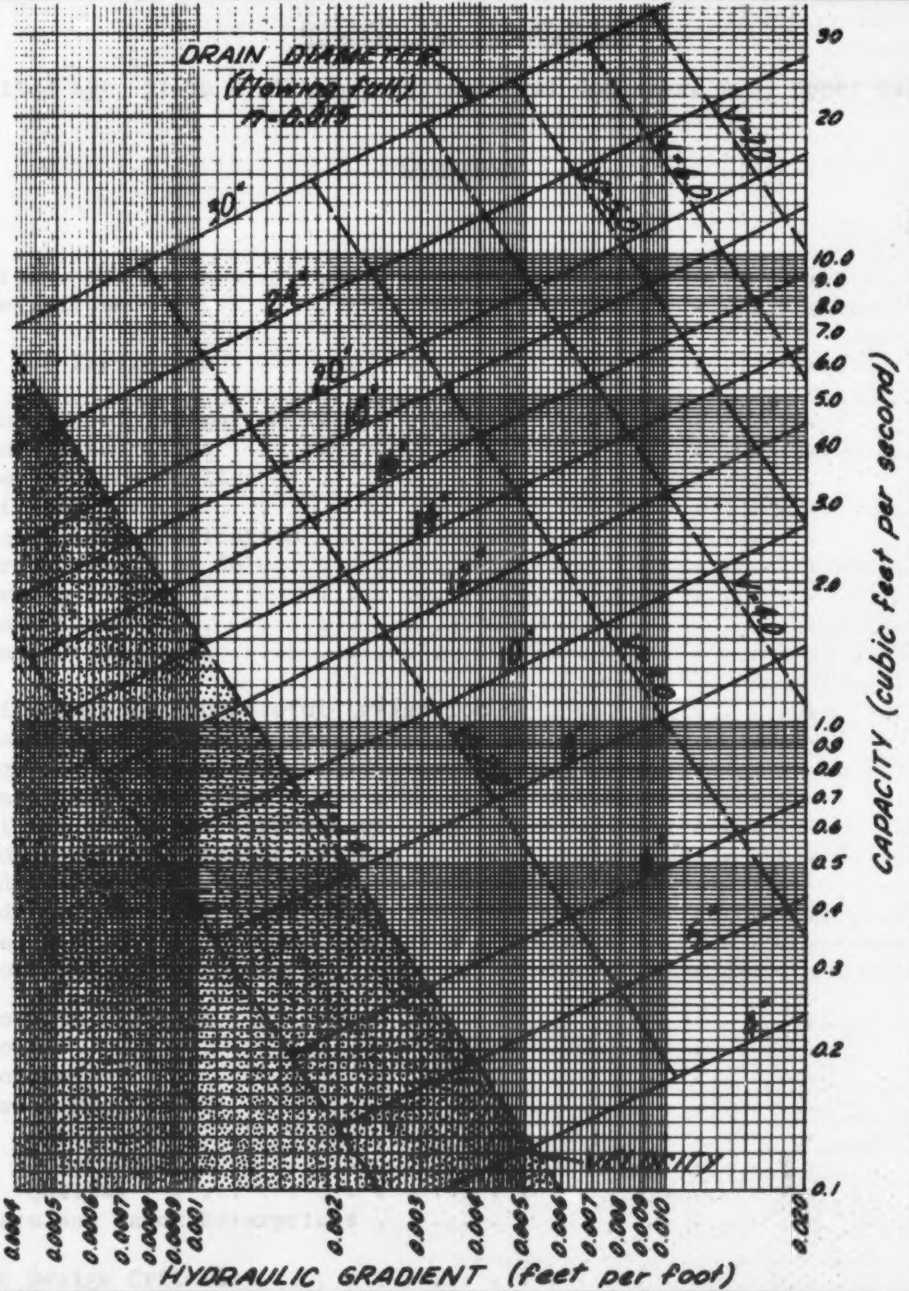


Exhibit 14-12 Curves to determine discharge

DRAIN CAPACITY CHART — n = 0.015



REFERENCE: This chart was developed by Guy B. Fasken.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DRAINAGE SECTION

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ES - 721
SHEET 3 OF 3
DATE 8-3-70

Exhibit 14-13 Chart for determining required size of corrugated plastic drainage tubing

ENGINEERING FIELD MANUAL

CHAPTER 15. IRRIGATION

Compiled by: Glenn E. Stucky, Agricultural Engineer, SCS, Upper Darby, Pa.

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ENGINEERING FIELD MANUAL

CHAPTER 15. IRRIGATION

1. GENERAL

DEFINITION

Irrigation is the application of water to the land to eliminate the moisture limitation to crop production. The practice includes the development of the water supply, the conveyance system, the method of application and the waste water disposal system, along with the necessary management to achieve the intended purpose.

2. NEED FOR IRRIGATION

The need for irrigation arises because rainfall frequently does not occur at the right time or in the right amount to satisfy crop needs. Ideal rainfall distribution seldom occurs during the growing season In the more arid portions of the United States the growing season rainfall is far short of most crop needs. Even in areas of high seasonal rainfall, crops often suffer from a lack of moisture for short periods during some part of the growing season. From the standpoint of crop quality and production these periods are drought periods.

A drought period may be defined as any number of consecutive days in which the available moisture in the soil profile has been so reduced by plant use and surface evaporation that growth and quality are adversely affected. The time interval between the presence of a maximum supply of available moisture and the beginning of a drought period will vary widely. This interval depends upon the ability of soil to store moisture, the rooting habits of the crop, and the rate at which the crop is transpiring moisture. Refer to Chapters 1 and 3, Section 15, SCS National Engineering Handbook.

3. ADVANTAGES OF IRRIGATION

Many benefits are obtained from the proper use of irrigation, such as:

INCREASED YIELDS

When moisture otherwise would be a limiting factor in crop production, irrigation can be expected to increase crop yields.

BETTER CROP QUALITY

By careful control of the amount of moisture in the soil, higher quality crops, demanding higher market prices, can be produced each year.

Examples are: the use of irrigation water to counteract high or low temperatures; elimination of short droughts that reduce quality; or withholding irrigation during the curing-out period prior to harvest.

TIME OF HARVEST

In many highly competitive areas, the difference between profit and loss often depends on the time certain crops are put on the market. Proper irrigation will insure prompt germination and continuous plant growth, making it possible to regulate planting dates and time of maturity more closely. This applies, for the most part, to fruits and vegetables.

FERTILIZER APPLICATION

Fertilizers do not aid plant growth unless moisture is available. With irrigation, plant food fertilizers can be made available for use almost immediately and increased amounts of fertilizer may be utilized. The application of soluble fertilizers through irrigation water is becoming a common practice. With sprinkler irrigation this method offers a saving in labor, requires a minimum of fertilizing equipment, and the depth of penetration can be closely controlled.

PROTECTION FROM COLD

High-value cash crops, such as strawberries, cranberries, tomatoes, and some vegetable crops, can be provided limited protection from frost and freeze damage through water applications just prior to and during periods of freezing temperatures.

TRANSPLANTING

The application of irrigation water immediately following transplanting greatly increases plant survival, thus reducing transplanting costs. The water settles the soil into close contact with the root system. Sometimes an application is made just before transplanting when the soil is not up to field capacity.

FARM ECONOMY

Where adapted, irrigation serves to stabilize yields. The cost of conducting farming operations has increased so much that few farmers can afford even one crop failure. Seed, fertilizers, equipment, and labor can be more fully used under irrigation.

LAND UTILIZATION

Efficient irrigation permits better use of land in accordance with its capabilities. Since increased yields from good land can be obtained through high fertility and adequate moisture, the use of more erodible land for grass and legume production will become more feasible and practical. Irrigation also makes possible the seeding and prompt germination of soil improvement crops at the proper time during the growing season and helps to establish vegetative cover on eroded areas.

For additional guidance on application of fertilizers, soil amendments, and frost control see National Engineering Handbook, Section 15, Chapter 11.

4. REQUIREMENTS FOR SUCCESSFUL IRRIGATION

Irrigation should be undertaken only after evaluating all factors relating to costs and returns. For the farmer, the benefits from irrigation must be sufficient to justify the cost of purchasing, installing and operating the irrigation system and leave a reasonable return on the investment. For the greenskeeper, park or landscape superintendent, nurseryman, and homeowner, irrigation must be done to maintain the desired growth of grass, ornamental plants, flowers, and garden crops with minimum cost and effort.

To obtain maximum benefits from irrigation, the following factors must be favorable:

WATER SUPPLY

Irrigation requires large volumes of water. Where the water supply is from a source developed on the farm, the landowner should assure himself that the supply is:

1. Adequate for the crop requirements on the acreage to be irrigated.
2. Economically accessible.
3. Of suitable quality.
4. Legally available.

LAND PRODUCTIVITY

Other things being equal, the greatest increase in crop yields may be expected when the most productive land is irrigated. For this reason, irrigation should be confined to those soils that are shown in the Technical Guides to be capable of producing sustained high yields of adapted crops when properly treated and managed.

FERTILITY MANAGEMENT

When the soil fertility is below optimum, it should be improved by the use of fertilizers and soil improvement crops to fully utilize available moisture assured by irrigation.

PLANTS AND PLANT POPULATIONS

In order to obtain the greatest irrigation benefits, high quality seed, adapted plant varieties, and proper plant populations should be used.

CONSERVATION CROPPING SYSTEMS

The sequence of crops grown and the use of crop residues and cover crops are important considerations in obtaining maximum returns. These practices improve soil structure and maintain or improve soil intake characteristics. Good cultural practices are necessary for the control of weeds, insects, and plant diseases.

ADEQUATE LABOR

The addition of irrigation to other farm operations materially increases labor requirements on most farms. Oftentimes labor will be required for the irrigation of one or more crops at a time when other crops must be planted, cultivated, or harvested. A study of available labor must be made while planning an irrigation system. The size of the irrigation operations should be no larger than that for which labor is assured.

ADEQUATE CAPITAL

Irrigation is a relatively expensive practice compared with most farm operations. This fact should be kept in mind when considering irrigation. The owner must be able to make an initial capital investment adequate to install a well-designed system planned to meet his individual needs. He must have sufficient capital to operate and maintain the system at least until the first year's irrigated crop is marketed. It is often necessary and advisable for the farmer to reduce the acreage originally intended for irrigation to an acreage more in line with his available funds.

RELATIONSHIP TO EROSION CONTROL AND DRAINAGE

The planner is faced with the problem of simultaneously meeting the three following requirements:

1. Efficient water application without erosion from the applied water.
2. Protection against erosion from rainfall.
3. Providing required surface and subsurface drainage.

The physical layout requirements for the proper application of irrigation water are often directly opposed to the physical requirements for protecting the land against damaging erosion from rainfall. This is especially true with surface methods of irrigation. To protect a field from storm erosion, it is often desirable to lay out the rows so the furrows are nearly level; while for water application it may be easier to install a less efficient system by running the rows directly down the slope. Slope modification through the use of contour irrigation with or without terraces and contour bench leveling is often used to satisfy both requirements. In other instances, conventional erosion control practices are applied and the irrigation water is applied by sprinklers.

Similarly, the needs for drainage and irrigation are not necessarily alike. On some soils it might be desirable to apply irrigation water by ponding methods, such as by the use of level borders, but such a practice might not be compatible with the drainage requirement for the removal of excess storm water. On the other hand, land leveling for irrigation in many instances will aid the surface drainage of a field through the elimination of small ponded areas.

The application of irrigation water may change the balance between recharge and discharge of the ground water, which may result in changes in the elevation of the water table. Usually when water is diverted onto an area from an outside source, the water table rises and may reach a point where subsurface drainage is required. When irrigation water is pumped from the water table, the water table may drop. When subirrigation is the method of applying water, subsurface drainage must necessarily be of a controlled type.

When the planner has met the requirements for efficient irrigation application, effective erosion control and adequate surface and subsurface drainage, he has developed a plan which sets the framework for conservation irrigation by the farmer.

GOOD DESIGN AND OPERATION

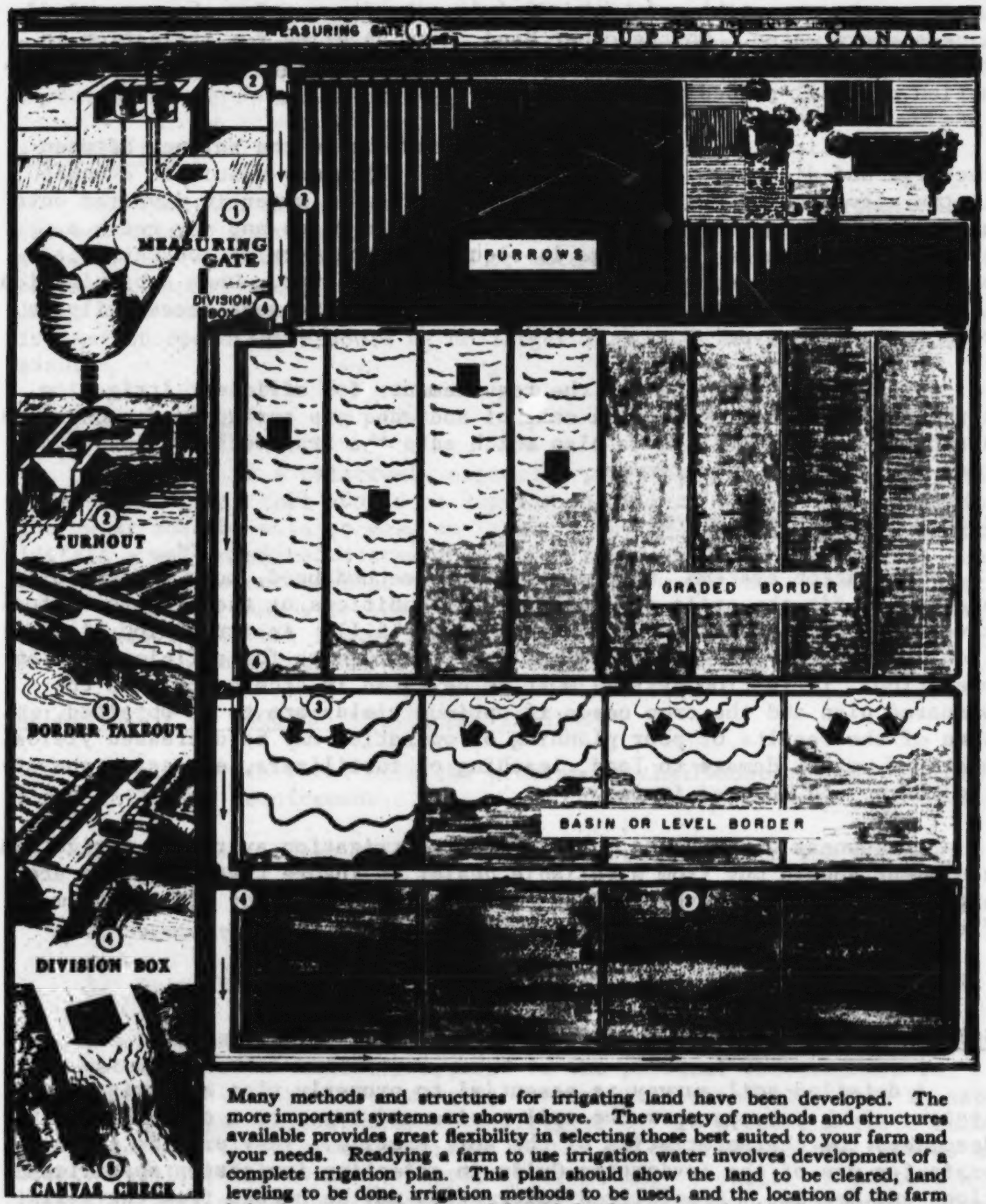
Irrigation systems, regardless of the method used, must be carefully planned to fit the soils and topographic conditions of the site for effective and efficient use of water (see Figure 15-1). An irrigation plan should set forth the specifications and requirements for efficient system operation. Irrigation systems must be operated in accordance with the prepared plan and the crop needs if optimum yields are to be obtained. Some of the results of poor planning or operation may be decreased yields, waste of water, damage to land, leaching of fertilizers, excessive operating costs, and lowered income.

Landowners who plan to buy a complete irrigation system or irrigation equipment should buy from a reliable dealer to insure that all parts are engineered to fit together. Used equipment that does not fit the farm or field generally results in inefficient operations.

5. FACTORS IN PLANNING

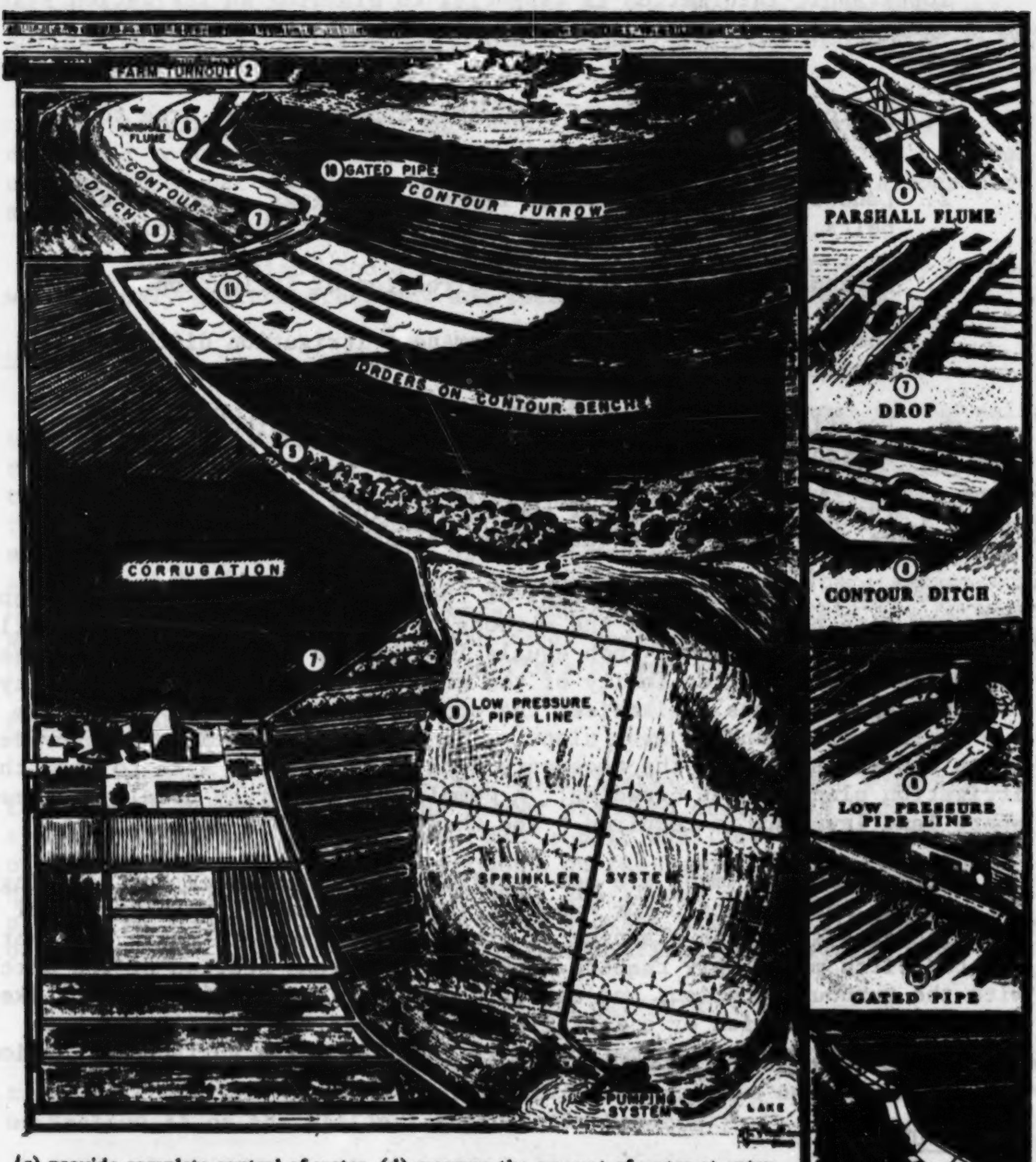
SOILS

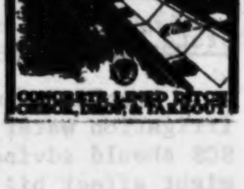
A detailed soil survey is essential to properly plan an irrigation system. Such surveys show the soil series and type, or a code which describes the characteristics of the soil profile. They provide the basis for use of the Irrigation Guide in selecting irrigation specifications and methods. Specialized information may be needed from the soil scientist on local soil conditions which may affect an irrigation plan.


MEASURING GATE ①
SUPPLY CANAL
②
②
①
MEASURING GATE
DIVISION BOX ④
FURROWS
GRADED BORDER
④
③
BASIN OR LEVEL BORDER
④
③
② TURNOUT
③ BORDER TAKEOUT
④ DIVISION BOX
⑤ CANVAS CHECK

Many methods and structures for irrigating land have been developed. The more important systems are shown above. The variety of methods and structures available provides great flexibility in selecting those best suited to your farm and your needs. Readying a farm to use irrigation water involves development of a complete irrigation plan. This plan should show the land to be cleared, land leveling to be done, irrigation methods to be used, and the location of the farm irrigation structures. A good farm irrigation system should efficiently perform the following functions: (a) deliver water to all parts of the farm when needed, (b) deliver water in amounts needed to meet crop demands during peak use periods,

Figure 15-1 Some elements considered


FARM TURNOUT 2
PARSHALL FLUME 6
10 GATED PIPE
CONTOUR FURROW
CONTOUR DITCH 8
7
11
BORDERS ON CONTOUR BENCHES
5
CORRUGATION
7
9 LOW PRESSURE PIPE LINE
SPRINKLER SYSTEM
PUMPING SYSTEM
LAKE
6 PARSHALL FLUME
7 DROP
8 CONTOUR DITCH
9 LOW PRESSURE PIPE LINE
10 GATED PIPE


CONCRETE LINED DITCH
CHECK, DROP, & TAKEOUT

(c) provide complete control of water, (d) measure the amount of water at entry into farm irrigation system, (e) divide water in required amounts for use in different fields, (f) dispose of waste water, (g) provide for reuse of water on the farm, (h) allow free, easy movement of farm machinery, and (i) distribute water evenly into the soil of each field. In performing these functions, conservation of the water and land resources is a basic consideration. Irrigation and cropping methods that best fit the particular soil, slope, crop and water supply should be used. This is conservation irrigation and it makes possible irrigation without: soil erosion damage, saline or alkaline accumulation, water logging, or undue water loss.

in irrigation planning

TOPOGRAPHY

Topographic information is essential to planning an irrigation system. As a minimum, surveys should include enough detail to show or plan the following:

1. Source and elevation of the water supply for the area to be irrigated.
2. Landscape features such as fences, buildings, roads, shelterbelts, etc., that may affect the design of the system.
3. Present field boundaries and direction of irrigation.
4. Location and capacities of permanent irrigation ditches, pipelines and structures.
5. Location and capacities of temporary field ditches or portable pipes and flumes.
6. The drainage pattern of the farm including the location and capacities of waste water disposal ditches and structures.

The scale and contour interval of topographic maps will vary, depending upon site conditions and the methods of irrigation under consideration. The scale may range from 1 inch equals 100 feet to 1 inch equals 400 feet, depending upon the irregularity of the ground surfaces and the intensity of landscape features. Likewise, the contour interval might range from 0.5 to 10 feet depending upon slope. The objective should be to provide a map containing all of the necessary data in sufficient size to show the irrigation plan without crowding. A complete grid survey usually is needed where land leveling is required. See Chapter 1 of this manual.

Grid or contour maps are not required in all instances for planning irrigation improvements. For example, in the partial reorganization of an existing system, the planning of grade control structures in a properly located ditch might only require a profile and cross section of the ditch with the turnout locations and elevations to field laterals noted. Likewise, the installation of a sprinkler system does not require the same detail of topographic information as is required for a surface irrigation system.

WATER SUPPLY

State Laws

Compliance with State Laws in obtaining water rights and in using irrigation water is the responsibility of the cooperator. However, the SCS should advise the farmer as to the existence of water laws which might affect his plan or installation, and encourage him to seek interpretation of a law or advice on a legal problem from a lawyer.

Quantity

The quantity of water available for irrigation must be determined. If the source of the water is from a reservoir, the acre-feet available during the season should be determined. See Table 11-2 of Chapter 11 of this manual.

It is also important to know the rate at which the water can be delivered to the farm. This rate usually is expressed in miner's inches or cubic feet per second at the headgate or diversion or in gallons per minute, if from a pump.

An investigation should be made to determine the reliability of the water supply and the frequency and season of expected shortages.

Quality

When irrigation water is transpired by the plants, most of the salts that were in the water may remain in the soil unless there is sufficient rainfall, or excess water is provided to leach the salts downward. The total concentration of soluble salts, the relative proportion of sodium to other cations, the presence of toxic amounts of boron or other elements, and the relative concentration of bicarbonates to calcium and magnesium should be determined. Facilities are available through State Agricultural Colleges, Public Health Departments, and commercial laboratories to test water quality. In areas where the water quality is not known, tests should be made and evaluated by soil scientists or specialists.

FARM AND RANCH ENTERPRISES

An investigation for planning an irrigated farm is not complete until the type of enterprise that the farmer plans to develop is known. The types of crops to be grown, the labor supply available and the intensity of the operation all have an influence on the layout. The irrigator may have an opinion as to the best methods and layout. It is the job of the planner to suggest alternates so as to provide a sound basis for his final decision. See Chapter 3, Section 15, SCS National Engineering Handbook.

6. BASIC DESIGN CRITERIA

Design criteria for each of the methods of irrigation water application are contained in State Irrigation Guides and the appropriate chapters of Section 15 of the National Engineering Handbook.

Design criteria for each irrigation practice listed in the National Catalog of Practices are found in Engineering Practice Standards and Specifications for each state.

7. CONSERVATION IRRIGATION METHODS

LEVEL BORDERS

The level border method of irrigation consists of surrounding a nearly level area with a low dike and quickly filling the area with the desired amount of water. A temporary pond is created until the water is absorbed by the soil.

Both row crops and close grown crops are adapted to use with level borders as long as the crop is not affected by temporary inundation or is planted on beds so that it will remain above the water level.

As the intake rate of the soil increases, the stream size must be increased or the run lengths shortened in order for water to cover the area within the correct period of time. Large irrigation streams usually require higher border ridges. However, they can be used if the conditions specified in the guide can be met.

Level borders are useful when leaching is required to remove salts from the soil profile.

The area within a level border must be carefully leveled. Preferably there should be no cross slope and the total fall within the length of the border should not exceed half the normal net water application depth.

GRADED BORDERS

With the graded border method of irrigation, the field is divided into rectangular parallel strips separated by small earth dikes called border ridges. These ridges are broad and low enough so that they can be planted and harvested with the rest of the field.

The graded border method is adapted to close growing crops. A stream of water is introduced into the upper end and it flows across the field in a sheet between the border dikes. By selecting the proper stream size, efficient irrigation application results.

Border strips should not have more than 0.1 foot of cross slope. Thus, on a field which has been leveled to a cross slope of 0.3 percent, the borders should not be more than 33 feet wide while with a cross slope of 0.2 percent, 50-foot wide borders may be used. When possible, the cross slope should be zero.

Ideally graded borders should have a uniform slope in a downfield direction. When this is not possible, the steepest slope should not be greater than twice the flattest and the slope should either steadily increase or decrease in a downstream direction. Undulating slopes are inefficient.

FURROWS

The furrow method of irrigation is used in the irrigation of row crops with furrows developed between the rows in the planting and cultivating processes.

For the best irrigation efficiency with the graded furrow method, the largest practical stream should be used to force the water across the field and then the stream should be cut back to the size which will keep runoff losses to a minimum for the balance of the irrigation. With level furrows, the initial stream should be used until the required amount of water is applied. The water should be ponded in the furrows until it is absorbed by the soil. The maximum stream size which may be used depends upon the size, shape and slope of graded furrows. From an erosion standpoint, the maximum stream in g.p.m. usually should not exceed the value of 10 divided by the slope in percent.

In general, furrows run down the slope; however, on smooth, uniform sloping fields, crops can be planted across the slope to reduce furrow grade. Also, on this type of slope it is sometimes desirable to have the rows parallel to a fence or other boundary which makes the rows run across the slope. This is satisfactory as long as the furrows are deep enough and the soil stable enough so that irrigation water or storm runoff does not break over from one furrow to another.

CONTOUR FURROWS

Contour furrows may be used on moderately steep slopes when medium deep furrows can be developed. They may be installed along with terraces on lands which require terraces for protection against erosion.

The planting of contour furrows must be carefully done. When the guidelines or terraces spread apart in the direction of flow, the lower guideline should be followed; when they come closer together, the rows are made parallel to the upper guideline. This insures that every furrow has a grade at least equal to the grade of the guideline or terrace.

CORRUGATIONS

Corrugations are identical with furrows except they are used with close grown crops and may be spaced in accordance with the properties of the soil instead of the requirements of the crop.

Corrugations may be used with other methods to facilitate the spread of water or to reduce crusting damage. They also are used between borders to irrigate a crop up or to guide water to small ridges between contour ditches. When used in this manner the system design is not based upon the specifications for corrugations but rather upon the specifications for the methods which they facilitate.

CONTOUR DITCH

The contour ditch method is widely used for irrigating close grown crops on steep slopes. With this method ditches are laid out across the slope on a slight grade. Water is released from the ditches by means of siphon tubes or openings in the ditchbank. Plowing of a furrow on the lower side of the graded contour ditch and throwing the furrow against the lower bank is a simple improvement that allows more uniform distribution of flow and generally increases the efficiency of this method.

SPRINKLER

The sprinkler method applies the irrigation water by means of a spray somewhat resembling rainfall. Sprinkler systems are normally designed by the company which sells them and to do an adequate job they need to know several things with respect to the site conditions. The Irrigation Guide will give the following required information:

1. The soil-slope group adapted to sprinklers.
2. The peak consumptive use rate.
3. Maximum allowable sprinkler application rate.
4. Net moisture to be replaced.
5. The estimated application efficiency.

The time of application depends upon the rate at which the water is applied, so no figure is shown in the Irrigation Guide.

SUBIRRIGATION

The subirrigation method requires rather special site conditions since it is necessary to have complete control of the water table through control of water application and drainage. For this reason the method is seldom mentioned in the Irrigation Guide. Each site requires special investigations and problems of this nature should be referred to the Engineering Specialists.

8. WATER CONVEYANCE

CAPACITY

Irrigation water must be conveyed from its source through a system of canals, pipelines, structures, etc., to the individual furrow border or sprinkler head. On projects or group systems a canal system usually delivers the required flow to the farm headgate. The plan must provide conveyance from the headgate or farm source to the individual field and furrow. The conveyance system must have a capacity to deliver to the field a flow:

1. Adequate to meet the consumptive use of the crops to be grown in the field with provision made for the expected field irrigation efficiency.
2. Adequate to meet the largest size of stream required for the irrigation methods planned for the field.

There will be some waste in getting the water from the headgate or pump to the field. If the water is carried in buried or surface pipelines this loss may be negligible. In lined ditches the loss will also be very slight, depending upon the type of lining and its condition. Water conveyed in open unlined ditches may have considerable loss, sometimes 20 percent to 50 percent per mile or more on permeable soils. When unlined ditches are used, the farm requirement is equal to the field requirement plus the amount of the ditch losses.

OPEN DITCHES

Capacities and dimensions of permanent open ditches are given in Exhibit 15-1. A ditch should be selected which will safety convey the required stream.

In designing a permanent ditch, a profile of the centerline showing the location and elevation of the water supply and any required turnouts, crossings, drainage bypasses, etc., is required. To provide an adequate irrigating head the water surface should be at least 0.5 foot above the field surface at all delivery points. Refer to Chapter 3, Section 15, National Engineering Handbook for information on lined and unlined ditches.

STRUCTURES

In the selection of a specific structure, the depth of flow "d" should always equal the depth of flow in the ditch and the structure capacity should equal or exceed the design flow capacity of the ditch. Standard structures should be used wherever possible. When a special design is required the job should be designed in cooperation with someone having the job approval authority for this work.

Criteria for certain types of irrigation structures are given in Chapter 6 of this manual. These criteria may be used to determine if a structure is adequate, even though not built according to an SCS standard plan. In most instances it is desirable to exceed minimum requirements to provide longer life, better operation or easier construction. Whenever possible the farmers and contractors should be encouraged to utilize the standard plans already available.

DROPS

Drops should be placed in a ditch line when the velocity of the water exceeds the allowable velocity. Canals lined with Bentonite or clay should have velocities not to exceed 1.5 feet per second or, if covered, the permissible velocity for the exposed material. It is recommended that velocities in concrete lined ditches should be held below 10 feet per second.

Drop structures should be placed so that, if desired, they can be used to divert water onto the land. A good rule to use for the location is to place the structure about 10 or 15 feet downstream from the point where the water surface is 0.5 foot above the graded land surface. This procedure appears to place the structures on fill, but since the line represents the water surface and not the ditch bottom actually the structure will always be on firm ground.

The height of drop structures used to lower water from one control point to another should be based on the economics involved and the desires of the farmer. Since two smaller drops take more materials and labor than one larger structure, the tendency in newly irrigated areas is to use fewer, higher drops and keep the cost down. In many of the older irrigated areas the tendency is to use more small drops to eliminate deep ditches between structures. For small farm ditches the height of the drop in feet should not exceed the land slope in percent. A drop over three feet in height should seldom be used. With large streams this height is sometimes increased. On steep slopes it is often advisable to use a concrete-lined ditch section or pipeline to lower the water.

Turnouts

Turnouts should be placed so that it is not necessary to check the water above the design flow of the ditch. This will provide a factor of safety should water be turned down the ditch with the check flashboards still in place.

Crossings

Crossings should be provided to permit access of equipment to all parts of the field. With pipe drop structures, a crossing can be provided by extending the length of the barrel and increasing the width of the fill.

PIPELINES

Irrigation pipelines can be used for the same purposes or in place of open channels. Water distribution efficiency is high as they almost eliminate losses from evaporation and seepage. They are particularly adapted to areas where seepage losses from ditches are high. Pipelines have an advantage over open ditches in places difficult to excavate and, where necessary to carry water down steep slopes. Pipelines require careful planning for the correct location, capacity requirements, selection of materials and construction methods. Generally the services of an engineer are required. Chapter 3, Section 15, National Engineering Handbook gives further information on pipelines.

MEASURING DEVICES

Some type of measuring device is needed so the farmer will know how much water he is using and can make the necessary adjustments to provide for efficient use of water. The simplest of all measuring devices is a weir, but it requires a considerable drop or loss of head to function accurately. When such a head loss cannot be tolerated, a Parshall flume or trapezoidal flume may be used. Usually large ditch companies have a measuring device built into the headgate. Some pumping installations are equipped with meters on the discharge line.

9. LAND LEVELING

It is often necessary to modify the topography of the land to provide more efficient application of irrigation water by surface methods. Such modification, made according to a plan providing for specific elevations at each point, is called land leveling.

The relief classes for surface irrigated land are shown in Exhibit 15-2. When the surface relief meets the standards for Class D or E, possible irrigation water efficiencies would be poor or very poor, and leveling would be required for conservation irrigation. The ideal land surface for surface irrigation is one that has little or no cross slope; a uniform down field slope that is slight enough so that erosion from rainfall and irrigation water is not a problem; and a slope steep enough to provide good surface drainage. The slope limitations vary from location to location because of differences in soil and rainfall conditions.

Occasionally fields are found which are ideal in these respects and no leveling is required. Usually, however, it is necessary to do some leveling on each field. Over the years the standards of what is a satisfactory leveling job have gone up and farmers are finding it worthwhile to relevel fields that once were considered very satisfactory. Many irrigation areas that are presently being leveled to a "C" class probably will eventually want to go to "B" or even "A" class relief. For this reason the planner should sell the farmer the best job he will buy at this time. Details of the procedure for designing, staking and leveling land can be found in the SCS National Engineering Handbook, Section 15, Chapter 12.

10. WATER DISPOSAL SYSTEM

A complete water disposal system should be planned for each irrigated farm. This disposal system should be able to convey storm runoff, and irrigation waste water to an outlet without damaging erosion.

The disposal system should be incorporated as a part of the drainage design on lands that require or have a subsurface drainage system. On lands that require only surface water disposal the drainage system should, when possible, be built at the same time the lands are leveled.

In many cases the disposal system will use waterways designed principally to carry storm runoff. When irrigation waste is to enter these waterways, special plantings and maintenance care often must be specified.

11. EQUIPMENT

In addition to sprinkler systems, the farmer has a wide choice of portable irrigation equipment from which to choose. This portable equipment has been developed to permit more accurate distribution of water and to reduce labor requirements.

CHECK DAMS

Several types of canvas, plastic and metal check dams are available for both lined and unlined ditches. These checks are designed to block the flow in a ditch just below the point where the water is to be turned out. They have the advantage that they can be placed at any location and are not in the way when a ditch needs to be cleaned or rebuilt. Most are adjustable so that the water can be held at some constant level.

SIPHON TUBES

Siphon tubes are widely used to withdraw water from an irrigation ditch. They range in size from 3/8 inch in diameter to large fabricated siphons which will carry as much as 2 cubic feet per second. The small tubes usually are used for furrow irrigation, although a number of them may be used together with the border or contour ditch method.

With furrows, the tube sizes usually are selected so that two or three tubes per furrow will deliver the maximum stream recommended for the slope being irrigated. After the water has crossed the field one tube is removed to provide the "cutback" stream. The approximate discharge of small aluminum siphon tubes is given in Exhibit 15-3. The head shown is the difference in height in the supply ditch and the centerline of the discharge end of the tube or the water level in the furrow when the discharge end is submerged.

GATED PIPE

Gated pipe is made of light weight metal with small gates spaced to match the furrows. The pipe comes in sections easy for one man to handle and is fitted with simple watertight connections. A slightly different product made of vinyl-coated glass, cloth, butyl, plastic or canvas hose and equipped with small outlets can be used for the same purpose. Gated pipe reduces water losses during conveyance and provides a positive control of the water to each individual furrow.

The head loss in a reach of gated pipe with the gates closed is computed the same as for any similar pipe. For the reach in which the gates are open, the friction is first computed as if the entire flow was carried the full length. The computed value is then multiplied by a factor which depends upon the number of outlets. This factor is given in Exhibit 15-4.

Some head is required at the last gate to produce flow through the gate. The required head depends upon the type of gate used and the desired flow. Usually it is less than one foot.

An example of a calculation on gated pipe follows. Assume that it is desired to carry 1,000 gallons per minute through an 8-inch gated pipe 1,300 feet long and to deliver 5 gallons per minute through each of the last 200 gates. Gates are spaced 3 for each 10 feet of pipe length.

What is the total head loss if 8-inch pipe has a friction loss of 2.47 feet per 100 for a flow of 1,000 g.p.m.?

Given:

Number of gates	200
Multiple gate factor (Exhibit 15-4)	0.33
Length of pipe with gates open	670 feet
Length of pipe with gates closed	630 feet

Solution:

Open line loss 6.70 x 2.47 x 0.33 = 5.5 feet
Closed line loss 6.30 x 2.47 = 15.6 feet
Total Loss = 21.1 feet

12. METHODS OF MEASURING OR ESTIMATING SOIL MOISTURE

To determine the required depth of irrigation water to be applied at any given time, the irrigator should first estimate or measure the amount of available moisture remaining in the soil profile within the root zone depth. There are several methods of measuring or estimating available moisture content. Additional information on their advantages and limitations are given in the SCS National Engineering Handbook, Section 15, Chapter 1.

SOIL SAMPLING AND DRYING

This involves sampling of the soil profile at desired depth increments at several locations in each soil type found in the field. The soil samples are weighed, dried, and weighed again. The difference in weight is equal to the weight of the moisture. Usually this is expressed as a percentage of the weight of the dry soil.

TENSIOMETER

The tensiometer consists essentially of a porous cup filled with water and connected by a continuous water column to a vacuum measuring device, either a gage or manometer. The cup is buried in the soil at the desired depth and measurements are read above ground on the vacuum indicator. These instruments measure soil moisture tension directly. A moisture characteristic curve for the particular soil being irrigated is required to convert moisture tension measurements into percentage of available moisture remaining in the profile.

ELECTRICAL INSTRUMENTS

Electrical instruments operate on the principal that a change in moisture content produces changes in some electrical property of the soil or of an instrument inserted in the soil. In most cases this property is electrical conductivity. Electrodes are permanently mounted in conductivity units, usually blocks made of nylon, fiber glass, or gypsum. These blocks are buried at the desired depth and changes in the moisture content of the soil are reflected by changes in the electrical resistance in the blocks. Resistance or conductance meters are used to measure this resistance. It is necessary to calibrate the blocks in the field by comparing the resistance readings with the soil moisture contents determined by oven drying samples taken from the same relative position as the blocks.

GAS PRESSURE INSTRUMENTS

Instruments such as the carbide moisture tester utilize the principle of chemical drying of the soil sample. A reagent such as calcium carbide is mixed with the moist soil sample within a sealed chamber. The chemical reaction of the reagent and the soil moisture produces acetylene gas. The gas pressure registers on a gage which is calibrated to indicate the wet weight moisture percentage of the soil. Convenient tables are available to convert these values to dry weight moisture percentages. The reaction and readings normally require about 3 minutes per sample.

FEEL AND APPEARANCE METHOD

This method is rather widely used to estimate the amount of available moisture remaining in the soil profile. Samples are taken from various depths and at several locations within the field with a soil auger or post-hole digger. The feel and appearance of the samples are compared with a table, or a guide such as Exhibit 15-5, and the soil moisture level thus estimated. With practice and experience the irrigator should be able to estimate the moisture level within 10 to 15 percent.

EVAPORATION PAN METHOD

This method uses the relationship of crop consumptive use to the evaporation from standard evaporation pans. Evaporation pan data are approximations of consumptive use and are not measurements of soil moisture. The amount of soil moisture used in a given period must be calculated. This is done by applying a factor for the crop to be irrigated to the depth of water evaporated from the pan during that period. This calculated amount then represents the soil moisture, in inches, used by the crop.

MOISTURE ACCOUNTING METHOD

Consumptive use values are used to maintain a daily inventory of the soil moisture remaining in the profile. Starting at a time when the moisture level in the soil profile is known, a "bookkeeping" system is set up whereby the computed consumptive use is subtracted daily from the recorded available moisture in the profile. Rainfall and irrigation amounts are added to the moisture balance on the days of their occurrence. The success of this method depends on accurate measurements of the water-holding capacity of the soil, determination of daily consumptive use rates, and measurement of rainfall and irrigation amounts.

13. CONSERVATION IRRIGATION WATER MANAGEMENT

INTRODUCTION

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without the waste of either water or soil. It involves applying water to meet the crop needs in amounts that can be held in the soil for crop use, and at rates that will not cause runoff and erosion damage.

Irrigation water management is something the irrigator does to regulate the application of water, not the facilities he employs. For example, an irrigator may install a headgate to control the flow of water onto a field. The headgate itself provides no water management. The water is managed when the irrigator opens the gate to deliver water to the field or closes the gate to stop delivery. It involves mental as well as physical acts. The irrigator must make certain decisions before he performs the physical acts of irrigating. He must decide when to open the gate, how far it should be opened and when it should be closed. In fact, the ability to make sound water management decisions is the most important aspect of conservation irrigation water management.

In order to make sound decisions, the irrigator must have an understanding of the basic principles involved. He must have a general idea of how water is held in the soil for plant use and how much water his soils hold. He needs to know how to judge when an irrigation is needed and how much is needed. He needs to have a general understanding of soil intake characteristics and of the required adjustments in stream sizes and time of water application needed to fit the intake rates of his soils.

The primary SCS objectives in the field of irrigation water management are to give farmers an understanding of conservation irrigation principles; to show them how they can judge the effectiveness of their own irrigation practices; and to help them make needed adjustments in old systems or install new systems. The remainder of this chapter provides guidance toward meeting these objectives.

BASIC SOIL-MOISTURE-PLANT RELATIONSHIPS

Available Moisture-Holding Capacities

In order to do a good job, an irrigator must have an understanding of the usable moisture-holding capacity of soils. The lack of this knowledge is the cause of a great deal of over-irrigation and waste of water.

When a soil is irrigated the water moves down through the voids or openings between the soil particles, forming a film around each individual soil grain. This film of water is tightly held around the soil grains when small amounts of water are available. When the amount of water increases the film becomes thicker and the surface tension decreases. If the films become so thick that their surface tension will no longer resist the pull of gravity the extra water moves on down in the soil. The amount of water that is held around the soil grains against the pull of gravity is called the "field capacity" of the soil. This is the moisture condition of a well drained soil a day or two after a thorough irrigation.

As plants use water from a soil the films around the soil grains become thinner and more tightly held. When the films become so thin that the plants can no longer pull the water from around the soil grains the soil is said to be at the "wilting point." The available moisture-holding capacity of a soil is the amount of water that can be held between the limits of field capacity and the wilting point.

While it may not be important that irrigators know how water is held in the soil for plant use, it is important that they know how much can be held and that there is a limit to the available moisture-holding capacity of every soil.

In irrigation work it is convenient to think of the moisture-holding capacity of soils in terms of inches depth of water per foot of soil depth. The moisture held in any given soil profile depth or crop root zone is the summation of the amounts held in each 1-foot increment of the total depth.

Many determinations of the moisture-holding capacities of soils have been made. The available moisture-holding capacities of some soils are shown in the Irrigation Guides that have been prepared for specific irrigation areas. For those soils not covered in the Irrigation Guides the available moisture-holding capacities can be estimated by reference to Table 15-1.

Table 15-1 General range of available moisture-holding capacities and average design values for normal soil conditions

Soil Texture	Available Moisture	
	Range In./ft.	Average In./ft.
Very coarse textured sands and fine sands	0.5 -1.0	0.75
Coarse textured loamy sands and loamy fine sands	0.75-1.25	1.0
Moderately coarse textured sandy loams and fine sandy loams	1.25-1.75	1.50
Medium textured very fine sandy loams, loam, and silt loams	1.5 -2.3	2.0
Moderately fine textured sandy clay loams, clay loams and silty clay loams	1.75-2.5	2.2
Fine textured sandy clays, silty clays and clay	1.6 -2.5	2.3

Crop Root Zone Depths

In the above discussion, available moisture-holding capacities were considered solely as a property of soils. The total amount of soil moisture held available for plant use in any soil is dependent upon the depth of the soil profile occupied by plant roots. This root zone depth may be limited by the characteristics of the soil profile, or it may be limited by the root development characteristics of the plant itself.

Consider, for example, a uniform medium textured soil underlain by an impervious hardpan at a depth of 3.5 feet. On this site the moisture supply that could be retained for use by deep rooted crops like alfalfa, tomatoes, or orchards would be limited by the soil depth to hardpan rather than by the normal root characteristics of the crop. On the other hand, for shallow rooted crops like ladino clover, onions, or lettuce, the moisture that could be retained for use would be limited by the crop root zones, which are less than 3.5 feet. These crops must obtain their moisture from the upper foot or two of the soil profile.

Rooting characteristics vary widely for different kinds of plants even under the most favorable soil conditions. Some will produce roots and extract water to depths of 10 feet or more. Others may be unable to obtain any significant amount of water from a depth greater than 1 foot. The normal root zone depths of mature irrigated crops for each soil group are shown in the local Irrigation Guide. Young plants will, of course, have shallower root zone depths than shown in the guide.

Plant Moisture Requirements

Plants must have a continuous supply of readily available moisture in order to maintain rapid, vigorous growth. However, it is not necessary, feasible, or even desirable, to attempt to keep the soil moisture in the root zone continually at field capacity. The objective of irrigation is to eliminate the moisture limitation to crop production. This can be done by providing at all times within the root zone of the crop a supply of soil moisture held at sufficiently low tension to be easily available for crop use. Experience indicates that moisture tension conditions usually will be satisfactory for good crop growth if irrigations are applied about the time one-third to one-half of the available moisture in the root zone has been used.

Plants wilt and die when the moisture in the entire root zone approaches the wilting point. Their growth may be slowed well before this moisture condition is reached. However, plants do not use water at a uniform rate from all portions of the root zone. They use water more slowly from the lower portions of the root zone than from the upper portion. Under normal irrigation conditions plants obtain about 40 percent of their water from the upper quarter of their root zone, 30 percent from the second quarter, 20 percent from the third quarter, and about 10 percent from the bottom quarter. Thus, the upper part of the root zone may be close to the wilting point while moisture is available at lower depths. To determine the true moisture conditions the whole root zone profile must be examined.

Consumptive Use Rates

The moisture used by plants plus the moisture evaporated directly from the field surface is called consumptive use. The amount of moisture consumptively used in an irrigated field on any given day is related to the air temperature, the number of daylight hours, the crop, and the stage of growth of the crop. Other factors such as wind and relative humidity also affect consumptive use rates. All crops have relatively low consumptive use rates when they are young. Their highest rates usually occur as they approach the stage of maximum vegetative development. For comparable stages of crop growth, consumptive use rates are greater on long, hot summer days than on short, cool spring or fall days.

Local Irrigation Guides show the estimated peak period consumptive use rates for the major crops grown in the area covered by the guides. During most of the irrigation season it would be expected that consumptive use rates would be lower than those shown in the guides.

As consumptive use rates indicate the rate of depletion of soil moisture, this information is helpful in estimating when irrigation will be needed.

EVALUATION PROCEDURE

The effectiveness of a farmer's irrigation water management practices can be determined from a few simple field observations. No matter what method of water application is employed, whether it be border, furrow, sprinkler, corrugation, or some other, certain principles apply.

1. Irrigations should be made when needed to maintain favorable soil moisture conditions for good crop growth.
2. The amount of water applied should be sufficient to bring the root zone profile up to field capacity but should not greatly exceed this requirement.
3. The water should be applied at a rate that will not cause waste or erosion.

An examination of a farmer's irrigation water management practices, then, should attempt to answer the following questions.

1. Is an irrigation needed?
2. What is the soil moisture deficiency?
3. How much water is being applied?
4. Is the irrigation causing erosion?
5. How uniformly is the applied water spread over the field?
6. How much of the water is infiltrated into the soil?

The first two questions are interrelated. A knowledge of the soil moisture deficiency (amount of water needed to refill the root zone profile to field capacity) is required in order to judge whether or not an irrigation is needed. Therefore, they might properly be considered together.

Need for Irrigation and Amount to Apply

The amount of moisture remaining in the root zone and the need for irrigation may be determined by using any of the instruments or methods described previously under the heading of "Methods of Measuring or Estimating Soil Moisture".

A rough estimate of the magnitude of the soil moisture deficiency also can be made from a knowledge of the pattern of consumptive use by the particular crop, if the number of days since the last irrigation is known. For example, in an area where the Irrigation Guide indicates the peak period consumptive use rate of a particular crop is about one-third inch per day during a hot dry period, the average soil moisture deficiency would be about 3 inches some 8 or 10 days after the last irrigation. During periods of more moderate weather conditions the moisture deficiency would not be expected to be so great. These kinds of estimates cannot be precise, but they are useful in checking the reasonableness of the estimates made by the soil sampling procedure outlined earlier.

The question, "Is an irrigation needed?",cannot always be answered precisely. Most crops should be irrigated before more than about half of the available moisture in the crop root zone has been used. This is a good criterion for one limit of moisture depletion.

Some crops, however, are thought to do better at higher moisture levels (less moisture deficiency at time of irrigation). Therefore, an irrigation may be needed well before half of the available moisture has been used. Generally, one may consider that the need for irrigation is doubtful for any crop until the soil moisture deficiency approaches one-third of the available moisture-holding capacity of the crop root zone. Special purpose irrigations, such as for seed germination, are exceptions to this general rule.

For most crops there are critical periods in the growing season when a high moisture level must be maintained to obtain high quality yields. The critical period generally occurs during the blooming or fruiting stage.

In determining the need for irrigation one must not overlook the possibility that some portions of the field may be drier than other portions. Sometimes, because of poor distribution of irrigation water, the soil moisture deficiency in one portion of the field may be considerably greater than in the other parts of the field. Also, the soil in one part of a field may have a smaller available moisture-holding capacity than the soils in another part. The moisture in one soil might be depleted to the 50-percent level long before the other soils approached that level. If such critical areas are of significant size, the decision as to when to irrigate should be based on the available moisture in the drier areas.

Amount of Water Applied

The amount of water required to refill the root zone profile (net irrigation requirement) usually is expressed in inches of depth. For ease in making comparisons, the amount of water actually delivered onto the field should be measured in the same terms. As it is not possible with surface irrigation to use a ruler to make a direct measurement of the depth applied, other kinds of measurements must be made to furnish data for calculating the average depth of application.

Irrigation water deliveries usually are measured in terms of rate of flow. The commonly used units of flow are gallon per minute (g.p.m.) and cubic foot per second (c.f.s.). The minor's inch (M.I.) is an old flow unit that is still used in some western states. Another unit sometimes used is million gallons per day (m.g.d.).

Rate of flow is a volume delivered in a given time interval. If a time interval is specified, flow units can be converted to volume units. For example, a stream of 1 cubic foot per second (flow rate) running for 1 hour (time interval) will deliver 3600 cubic feet (volume) of water. If this volume is spread evenly over an area of 1 acre (43,560 square feet), the depth will be 0.083 foot (3600/43,560) and the volume would be 0.083 acre-foot. This volume is equal to 0.083 x 12 = 0.99 acre-inch. For practical use in the field the volume can be considered to be 1.0 acre-inch.

The above conversion of flow rate to volume is the basis for a handy formula that should be known and well understood by all irrigators and by every technician working in an irrigated area.

One cubic foot per second (c.f.s.) for 1 hour = 1 acre-inch.

If flows are measured in gallons per minute, miner's inches, or million gallons per day, they can be converted to equivalent cubic feet per second by using the following approximate relationships:

One cubic foot per second (c.f.s.) = 450 gallons per minute (g.p.m.)
= 38.4 miner's inches in Colorado
= 40 miner's inches in Arizona, Montana, Nevada, Northern California, and Oregon

= 50 miner's inches in Idaho, Kansas, Nebraska, New Mexico, North Dakota, South Dakota, Southern California, Utah, and Washington
= 0.65 million gallons per day (m.g.d.)

These relationships also can be shown as follows:

$$\text{c.f.s.} = \frac{\text{g.p.m.}}{450} = \frac{\text{M.I.}}{38.4 \text{ or } 40 \text{ or } 50} = \frac{\text{m.g.d.}}{0.65}$$

After the volume of water delivered onto a field has been computed in terms of acre-inches, it is a simple matter to calculate the equivalent average depth over the field. Just divide the acre-inches by the number of acres covered. Thus, 5.0 acre-inches spread over a 2.0 acre field is equal to an average application depth of 2.5 inches, or

$$\text{d (inches)} = \frac{\text{Q (c.f.s.) or ac.-in. (per hr.) x T (hrs.)}}{\text{A (ac.)}}$$

Three quantities must be known to compute the average depth of water applied on a field. One is the size of the irrigation stream, the second is the time water is run onto the field, and the third is the area of the field. The following examples illustrate the computation procedure:

Example 1

Given:

Stream size = 4.0 c.f.s.
Irrigating time = 10 hours
Field area = 8 acres

Find the average inches depth applied:

Solution:

1.0 c.f.s. for 1 hour = 1.0 acre-inch
1.0 c.f.s. for 10 hours = 10 acre-inches
4.0 c.f.s. for 10 hours = 40 acre-inches

$$\frac{\text{40 acre-inches}}{\text{8 acres}} = \text{5.0 inches applied}$$

Example 2

Given:

Stream size = 375 g.p.m.
Irrigating time = 12 hours
Field length = 660 feet
Field width = 165 feet

Find the average inches depth applied:

Solution:

375 g.p.m./450 = 0.835 c.f.s.
0.835 c.f.s. for 1 hour = 0.835 acre-inches
0.835 c.f.s. for 12 hours = 10 acre-inches
660 feet x 165 feet = 108,900 square feet
108,900 square feet/43,560 = 2.5 acres

$$\frac{\text{10 acre-inches}}{\text{2.5 acres}} = \text{4.0 inches applied}$$

Example 3

Given:

Stream size = 18 g.p.m. (average per furrow)
Irrigating time = 24 hours
Field length = 1450 feet
Furrow spacing = 3 feet

Find the average inches depth applied:

Solution:

18 g.p.m./450 = 0.04 c.f.s.
0.04 c.f.s. for 1 hour = 0.04 acre-inch
0.04 c.f.s. for 24 hours = 0.96 acre-inch
1450 feet x 3 feet = 4350 square feet
4350 square feet/43,560 = 0.1 acre

$$\frac{0.96 \text{ acre-inch}}{0.1 \text{ acre}} = 9.6 \text{ inches applied}$$

Example 4

Given:

Stream size = 5.5 g.p.m. (average per sprinkler)
Irrigating time = 11.5 hours
Lateral spacing = 50 feet
Sprinkler spacing = 30 feet

Find the average inches depth applied:

Solution:

5.5 g.p.m./450 = 0.012 c.f.s.
0.012 c.f.s. for 1 hour = 0.012 acre-inch
0.012 c.f.s. for 11.5 hours = 0.138 acre-inch
50 feet x 30 feet = 1500 square feet
1500 square feet/43,560 = 0.034 acre

$$\frac{0.138 \text{ acre-inch}}{0.034 \text{ acre}} = 4.1 \text{ inches}$$

In all of the examples where the flow rate is given in terms of gallons per minute, the general form of the equation for depth (d), in inches, is as follows:

$$d = \frac{\text{flow (g.p.m.)} \times \text{time (hours)}}{\dfrac{450 \times \text{length (feet)} \times \text{width (feet)}}{43{,}560}}$$

$$d = \frac{\text{flow (g.p.m.) x time (hours) x 43,560}}{\text{length (feet) x width (feet) x 450}}$$

$$= \frac{\text{flow (g.p.m.) x time (hours) x 96.8}}{\text{length (feet) x width (feet)}}$$

Since 1 cubic foot per second flowing 1 hour is not exactly 1 acre-inch, and 1 cubic foot per second is not exactly 450 gallons per minute, the above equation for d is not exact. For exact conversions the factor 96.8 shown above should be 96.3. The error involved is only one-half of 1 percent, which is too small to be of concern. Most publications on sprinkler irrigation, however, do use the 96.3 value in converting sprinkler discharge to average depth. The conversion equation usually is shown as:

$$d = \frac{\text{sprinkler discharge (g.p.m.) x hours x 96.3}}{\text{lateral spacing (ft.) x sprinkler spacing (ft.)}}$$

Thus, for Example 4, the depth applied would be computed as:

$$d = \frac{5.5 \times 11.5 \times 96.3}{50 \times 30} = 4.1 \text{ inches}$$

Since lateral spacing times sprinkler spacing is just another way of saying length times width (equals area), the sprinkler conversion equation can be used for all situations where the flow rate is given in terms of gallons per minute. Example 2 can be used as an illustration.

$$d = \frac{375 \times 12 \times 96.3}{660 \times 165} = 4.0 \text{ inches}$$

In furrow irrigation work, the rate of flow as measured in individual furrows often is converted to average depth as follows:

$$d = \frac{\text{g.p.m. flow per 100 feet of furrow length x hours}}{\text{furrow spacing in feet}}$$

This is equivalent to:

$$d = \frac{\text{g.p.m. x hours x 100}}{\text{length x width (or spacing)}}$$

While this is less accurate than the other conversion methods discussed, the error is not great. It is slightly less than 4 percent.

Field Application Efficiency

The field application efficiency is determined by dividing the net amount of water needed to refill the root zone by the amount of water actually applied onto the field. Thus, if the net amount of moisture needed is 3.2 inches, and the amount applied is 5.0 inches, the field efficiency is 64 percent (3.2/5.0) = 0.64 = 64 percent.

A high efficiency does not always mean a good irrigation. The water may not have been distributed evenly over the field or the amount applied may not have been enough to bring the root zone up to field capacity. On the other hand, a low field efficiency usually means poor use of water and indicates a need for a careful check of the water management practices being used.

No sharp line can be set to separate high and low efficiencies. It is impossible to irrigate at an efficiency of 100 percent. Yet the further an irrigation departs from this ideal the more costly it becomes from the standpoint of water use, and the more apt it is to cause damage to the soil. In general, all irrigations should be made at the highest efficiency level that is practical and feasible. State Irrigation Guides give the percent efficiency which the average irrigator can expect to obtain, using good management on a properly designed and developed system.

Soil Erosion from Irrigation

Erosion is a hazard on most irrigated lands. Any irrigation that causes a significant amount of erosion cannot be considered satisfactory.

Serious erosion can occur with little or no soil being removed from the field. In surface methods of irrigation the irrigating streams are larger where they first enter the field. As they progress toward the lower end of the field they are reduced in size by the amount of water infiltrated into the soil. Often the large streams will erode the soil at the upper end of the field but have insufficient carrying capacity at the lower end to remove the material from the field. However, the opposite is true when erosion is caused by rainfall.

Erosion under surface methods of irrigation usually is greatest during the initial part of the irrigation. The dry surface soil, sometimes loosened by cultivation, is readily moved by the flowing water. After a short period of soaking, however, the soil settles and becomes more difficult to move. Under sprinkler irrigation the erosion pattern is apt to be reversed. At the start of an irrigation the intake rate may be higher than the application rate so no runoff or erosion will occur. Later in the irrigation period, however, the intake rate may become less than the application rate. If this occurs the water may begin to move over the surface and cause erosion. Sprinklers should be operated so that at no time does the application rate exceed the soil intake rate.

Under surface methods of irrigation some soil movement can be expected. However, irrigating streams should not be so large as to cut furrow side slopes, form rills in border strips, or cause other obvious movement of soil toward or off the lower end of the field. Though irrigation streams may be controlled to prevent erosion, measures may be needed to control erosion from rainfall, as pointed out under the heading "Relationship to Erosion Control and Drainage".

Uniformity of Application

An adequate irrigation is one that refills the root zone storage capacity throughout the field. To do this with a minimum amount of deep percolation loss, the water must be spread uniformly over the field so that each part of the field will have the same opportunity time to take in water. Opportunity time is the length of time that irrigation water is available at the ground surface for infiltration into the root zone.

The best way to tell whether a field has received an adequate irrigation is to check the soil moisture conditions a day or so after the irrigation. Dig or auger into the soil at representative spots to see if the root zone profile has been brought up to field capacity. If dry layers or spots are found, the irrigation was not completed or the water was not spread evenly.

For surface methods of irrigation, the uniformity of water distribution can be checked by determining how long the water is on the surface at various points along the length of run. If this length of time is about the same at all points, and the soils are similar, it can be assumed that each part of the field is getting about the same amount of water infiltrated into the soil. Usually a check on the opportunity time at the upper middle, and lower end of the run will be sufficient. However, the opportunity time at all points along the length of run can be determined by observing the time water reaches and recedes from selected points. These data are used to plot advance and recession curves as shown in Figure 15-2. The vertical distance between the advance curve and the recession curve at any point in the length of run is the "intake opportunity time" at that point. The opportunity time at all points should be sufficient to permit the desired amount of water to infiltrate into the soil.

Water Distribution in Furrows

Since the volume of water contained in a furrow, as temporary surface storage at the end of an irrigation, usually is relatively small, furrow recession curves are nearly flat. In other words, the water stops flowing at the lower end of the furrow within a few minutes after the water is turned off. See Figure 15-2. Therefore, to obtain good water distribution the "advance" period should be as short as possible.

Figure 15-2 shows an irrigation that meets the above criterion. In this example an intake opportunity time of 340 minutes is required to put the desired amount of water into the soil. It took 85 minutes for the furrow stream to reach the end of the run. The water was turned off 410 minutes after the start of irrigation and the water stopped flowing in the lower end of the furrow 15 minutes later.

The required intake opportunity time is shown by the dashed line drawn parallel to the advance curve. The shaded area above the dashed line indicates the excess intake opportunity time (deep percolation time). At the upper end of the run the deep percolation time is 70 minutes (410 - 340 = 70). In the center it is 53 minutes (393 - 340 = 53). There is no deep percolation time at the lower end of the run in this example.

The weighted average deep percolation time is 44 minutes (70/2 + 53 + 0 = 88; 88/2 = 44). This is 13 percent of the required 340 minutes of intake opportunity time. However, because intake rates decrease with time the average depth of water lost to deep percolation will be less

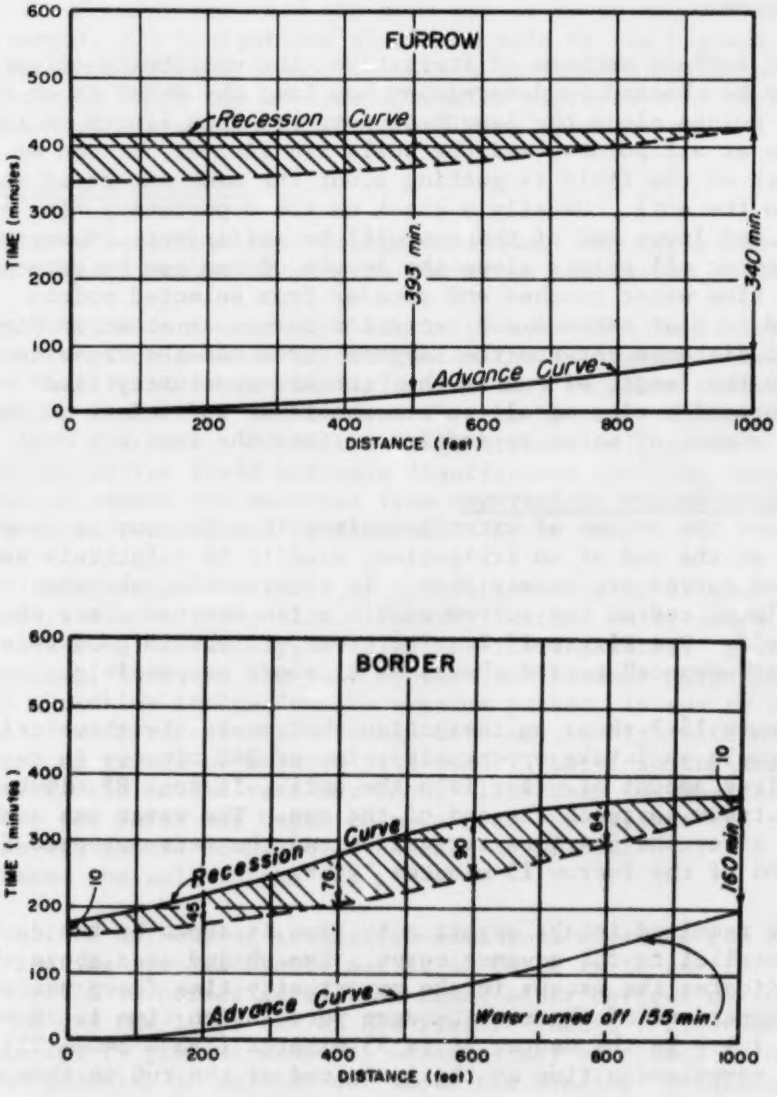


Figure 15-2 Sample advance and recession curves

than 13 percent of the depth needed to refill the soil profile.

Water Distribution in Graded Borders

In graded border irrigation, a relatively large volume of water is in temporary storage on the surface of the border strip at the time the water is turned off. In some cases, it may amount to more than half of the total volume run onto the strip. This water continues to be absorbed into the soil and some of it moves on down the strip to irrigate the lower end. This movement of water on the surface greatly prolongs the recession time at the lower end of the field. See Figure 15-2.

If the irrigating stream is properly adjusted for the intake characteristics of the soil, the required depth of application, and the border strip size, the recession curve will be roughly parallel to the advance curve. The two curves are said to be "balanced". Even under the most ideal conditions, however, the two curves are never exactly parallel. Therefore, in order to provide adequate intake opportunity time at all points in the length of run, there will be excess opportunity time at some points. Usually a good distribution of water will be achieved if the water is nearly across the field (close to the cutoff point) by the time the volume needed to fill the root zone has been turned into the border strip.

Figure 15-2 shows an irrigation that meets this criterion. In this example 160 minutes is required to put the desired amount of water into the soil. With the stream size used the needed volume of water would be delivered onto the strip in 125 minutes. At the end of this time the stream had advanced 750 feet. It was still 250 feet from the lower end. In order to provide sufficient intake opportunity time at the upper end of the run and furnish enough water to complete the irrigation at the lower end the flow was continued for an additional 30 minutes.

The required intake opportunity time is shown by the dashed line drawn parallel to the advance curve. The shaded area above the dashed line indicates the excess intake time when deep percolation will occur. In this example the deep percolation time varies from about 90 minutes in the middle portion of the run to 10 minutes at both the upper and lower ends. The weighted average deep percolation time is about 60 minutes ($\frac{10}{2} + 45 + 76 + 90 + 64 + \frac{10}{2} = 285$; $285/5 = 57$). The weighted average intake opportunity time, then, is 217 minutes ($160 + 57 = 217$). This is approximately 36 percent more time than required to infiltrate the desired amount of water into the soil. The total amount of water delivered onto the border was only 24 percent more than that required to refill the root zone (30 minutes/125 minutes = 0.24). With the distribution shown, the deep percolation could not exceed this amount. Also, some runoff occurred from the end of the border.

Water Distribution in Level Borders

In level border irrigation the amount of water required to provide the desired depth of application is ponded on a diked area of level, or nearly level, land until it can infiltrate into the soil. Like graded border irrigation, a large volume of water is in temporary storage on the surface of the strip at the time the water is turned off. However, level borders have no grade to cause this water to move toward the lower end of the run. Therefore, the recession curve is flat. In order to obtain good water distribution, the advance curve, too, should be made as flat as possible.

Level borders usually are designed to have an advance period of approximately one-fourth the required intake opportunity time. However, in some cases good distribution and acceptable efficiencies can be obtained where the time required for the water to fully cover the strip is considerably greater than one-fourth of the time required to infiltrate the desired amount of water into the soil.

Adjustments to Improve Distribution

In all surface methods of irrigation the uniformity of application is greatly dependent upon the size of the irrigating stream. On a given field a large stream will advance down the run in less time than a smaller stream. Therefore, if the intake opportunity time is found to be too great at the upper end of a run and too small at the lower end the stream size should be increased to flatten the advance curve. In cases where the stream cannot be increased the border width may have to be decreased the next time they are installed.

There is a limit to the size of stream that can be used. It must be kept within the erosion limits of the site. Also, it must not be so large it will overtop the furrows or the border ridges. If the stream size cannot safely be increased enough to provide good water distribution the length of run should be shortened.

In graded border irrigation the intake opportunity time may be too short at the upper end of the run and too great at the lower end. In this case the stream size should be reduced. This will increase the time needed to deliver the required volume of water onto the border strip and thus increase the intake opportunity time at the upper end of the run. Also, the smaller stream will require more time to advance down the border and this will reduce the intake opportunity time at the lower end of the run.

Tail Water Recovery

To obtain high efficiencies with surface irrigation it is generally necessary to permit some surface runoff at the lower end of the field, even under good management with cutback streams. In order to save this water, and prevent downstream damage, tail water recovery systems are becoming a common practice. Many cutback systems require a large amount of labor so many farmers are replacing the cutback technique with some type of tail water recovery. The tail water recovery system usually consists of collecting the runoff water in the tail ditch which diverts the water to a lower field for reuse or to a sump or storage basin. The stored water in the sump is then pumped through pipelines to a higher elevation for reuse.

Water Distribution with Sprinklers

The uniformity of water distribution on a sprinkler irrigated field can be checked by measuring the discharge of the first and last sprinklers on the lateral lines. Also, as the discharge of sprinklers is directly proportional to the square root of their nozzle pressure the uniformity can be checked by measuring the pressure at the first and last sprinklers. Thus, if the pressure at the first sprinkler is 50 p.s.i., and at the last sprinkler it is 40 p.s.i., the pressure at the first sprinkler is 1.25 times the pressure at the last sprinkler. The discharge of the first sprinkler is the square root of 1.25 times the discharge of the last sprinkler. The square root of 1.25 is 1.12. Therefore, the first sprinkler applies 12 percent more water than the last sprinkler.

Sprinkler Nozzles

The rate that water is being delivered to a field under sprinkler irrigation can be determined by measuring or estimating the discharge of one or more individual sprinklers. Volumetric measurements may be made by placing a hose or small tube over the sprinkler nozzle to direct the water into a container of known size, such as a 3-gallon or 5-gallon bucket. The time required to fill the container is measured with a stopwatch. After the time required to collect a given volume has been determined, the flow rate can be computed from the formula:

$$\text{Flow (g.p.m)} = \frac{60 \text{ x capacity of container in gallons}}{\text{number of seconds to fill}}$$

Thus, if 33 seconds are required to fill a 3-gallon bucket the flow rate is 5.45 g.p.m.

$$Q = \frac{60 \text{ x } 3}{33} = 5.45 \text{ g.p.m.}$$

Since sprinkler nozzle discharge is related to the pressure head at the nozzle a reasonable estimate of the flow rate can be made if the pressure is known. Most sprinkler manufacturers' catalogs contain tables showing the discharge of their sprinklers as related to pressure. For reliable estimates the pressure must be measured at or close to the nozzle.

In some instances it may be feasible to determine the discharge of each sprinkler on a lateral. Where this is done the values should be averaged to determine the average rate of application. One way is to measure the discharge of the first and last sprinkler on the lateral. The average discharge for all the sprinklers can then be computed as the discharge of the last sprinkler plus one-fourth of the difference between the first and last sprinklers.

Sometimes, because of topographic conditions, the minimum pressure may not occur at the last sprinkler. If the sprinkler lateral runs down the slope the minimum pressure might be at the first sprinkler. Where sprinkler laterals are not laid out on a nearly uniform grade the pressure or discharge should be measured at the high and low spots as well as at the end sprinklers.

The above measurements will indicate the overall distribution of water across the field. The uniformity of water distribution in the effective area of an individual sprinkler can best be determined by setting out a pattern of catch cans and measuring the depth of water caught. The cans should be set in a symmetrical pattern across the lateral between two sprinklers. The cans should be about 5 feet apart where the sprinklers' spacing is less than 30 feet. Ten-foot spacing is adequate where sprinklers are 30 feet or more apart. The procedure for making water distribution pattern tests is explained in Agricultural Handbook No. 82, "Methods for Evaluating Irrigation Systems".

Usually there is little need for making a distribution pattern test unless soil moisture tests after an irrigation, or the appearance of the crop, indicates an uneven distribution of water. If sprinkler spacing and nozzle pressures meet the criteria given in Chapter 11, Section 15 of the National Engineering Handbook, distribution patterns usually will be satisfactory.

Amount of Water Put into the Soil

Crop water needs are not satisfied by applying irrigation water onto a field unless the water is infiltrated into the soil and stored within the root zone depth where it will be available for use by the crop plants.

In some cases irrigation water applications are made in such a way as to produce no surface runoff. This is often true with sprinkler and level border or level furrow methods of irrigation. In such cases the average depth of water applied onto the field is also the average depth infiltrated into the soil. However, when surface runoff does occur it must be measured in order to determine the depth of water retained on the field.

The average depth of water infiltrated into the soil during an irrigation can best be determined by subtracting the volume of water lost by surface runoff from the total volume applied onto the field. This volume divided by the area of the field will be the average depth of water infiltrated.

On many fields surface runoff rates can be measured periodically in existing drainage or waste water ditches to furnish adequate data for the computation of runoff volume. Where site conditions make it infeasible to collect and measure runoff from an entire field, measurements of runoff rates from representative individual furrow or border strips may be used as an aid in estimating total runoff.

Runoff rates usually increase as intake rates decrease. Therefore, in order to determine the volume of surface runoff the rate of runoff usually must be measured at intervals throughout the runoff period. Runoff rates are converted to runoff volumes by use of the conversion formula: "One cubic foot per second flowing 1 hour equals 1 acre-inch". The procedure is the same as explained previously for computing the amount of water applied onto the field. However, with changing flow rates the computations must be made in steps. The volumes of runoff are computed for each time interval between measurements and summed to determine the total runoff. Table 15-2 shows a sample set of runoff calculations. In this example, the rate of flow onto the field is assumed to be 1.5 c.f.s. throughout

the 12-hour irrigating period. The total volume run onto the field, therefore, is 18 acre-inches (1.5 acre-inches per hour times 12 hours = 18.0 acre-inches).

Table 15-2 Computation of runoff volume

Clock Time	Measured Runoff (cfs=ac in/hr)	Average Flow Rate (ac in/hr)	Time Interval (hr)	Runoff Volume (ac in)	Remarks
08:15					Irrig starts (inflow=1.5cfs)
10:15	0.00				Runoff starts
		0.185	0.5	0.093	
10:45	0.37				
		0.410	0.5	0.205	
11:15	0.45				
		0.490	1.0	0.490	
12:15	0.53				
		0.585	2.0	1.170	
14:15	0.64				
		0.695	3.0	2.085	
17.15	0.75				
		0.785	3.0	2.355	
20:15	0.82				Irrig ends
		0.410	0.25	0.102	
20:30	0.00				Runoff ends
				6.500	Total runoff

For a field irrigated by a surface flooding method, such as borders, basins, or contour ditches, cylinder infiltrometers can be used to determine the amount of water put into the soil in a given period of time. Figure 15-3 is an example of an intake curve developed from cylinder infiltrometer data.

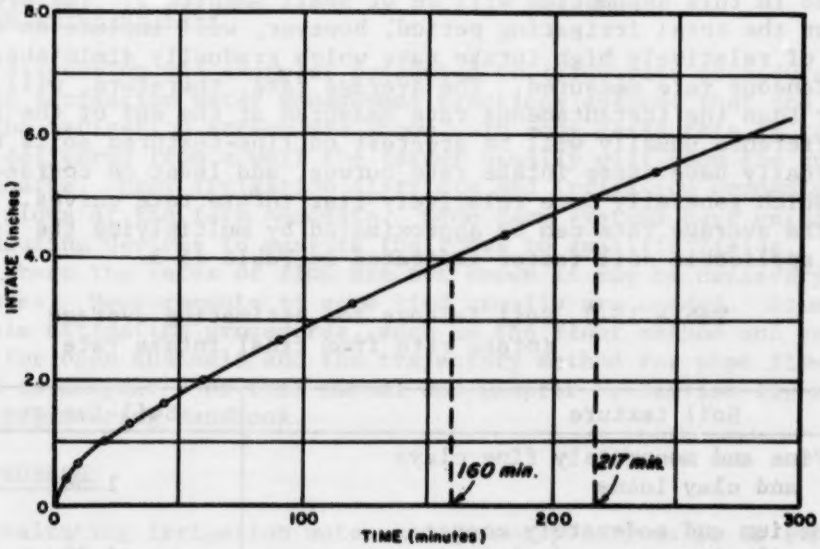


Figure 15-3 Sample intake curve

In order to use cylinder intake curves as a basis for estimating the average depth of water put into the soil the average intake opportunity time must be known. For example, if the sample intake curve shown in Figure 15-3 was developed on a bordered field having the the advance and recession characteristics illustrated by Figure 15-2, the average intake opportunity time would be 217 minutes (170/2 + 205 + 236 + 250 + 224 + 170/2 = 1085; 1085/5 = 217.) The weighted average depth of water infiltrated into the soil, then, would be 5.0 inches.

Figure 15-2 for borders also shows a minimum intake opportunity time of 160 minutes, which, from the intake curve, is sufficient to infiltrate 4.0 inches of water. Assuming this is the depth of water needed to refill the soil profile, the average deep percolation loss would be 1.0 inch.

For a field irrigated by furrows or corrugations, the average depth of water infiltrated into the soil can be estimated from a measurement of the instantaneous furrow intake rate. In order to use this procedure, the furrow intake rate should be determined by inflow-outflow measurements of individual furrows or of a group of furrows. The measurements should be made near the end of the irrigating period-- usually sometime in the last quarter of the period. The difference between the inflow rate and the outflow rate will represent the rate of furrow intake. The furrow intake rate should be expressed in terms of gallons per minute per 100 feet of furrow. It can then be converted to an equivalent field intake rate (inches per hour) by dividing by the furrow spacing (in feet).

The field intake rate thus determined can be considered the instantaneous rate at the end of the irrigation. There usually is very little change in rate during the last part of the irrigation period so any error involved in this assumption will be of small magnitude. The average intake rate for the total irrigating period, however, will include an initial period of relatively high intake rate which gradually diminishes to the instantaneous rate measured. The average rate, therefore, will always be greater than the instantaneous rate measured at the end of the irrigation. The difference usually will be greatest on fine-textured soils that characteristically have steep intake rate curves, and least on coarse-textured soils which generally have relatively flat intake rate curves. For most soils the average rate can be approximated by multiplying the final rate by the applicable soil factor indicated in Table 15-3.

Table 15-3 Soil factors for estimating average intake rate from final intake rate

Soil texture	Soil factor
Fine and moderately fine clays and clay loams	1.50
Medium and moderately coarse silt loam to sandy loam	1.33
Coarse and very coarse loamy sands and sands	1.20

The average intake rate multiplied by the average intake opportunity time will equal the average depth of water infiltrated into the soil.

The computations involved in estimating the average depth of water infiltrated into the soil from measurements of the instantaneous rate of intake is illustrated as follows:

Assume:

Moderately coarse-textured soil (factor = 1.33)	
Furrow spacing	= 3.0 feet
Total irrigating time	= 8.0 hours
Average intake opportunity time	= 6.9 hours

Intake rate measurements made on three representative furrow sections about 7 hours after start of irrigation.

Measurements and computations:

	Furrow number			
	1	2	3	
Inflow rate Sta. 0+00 - gpm	20.4	21.3	19.8	
Outflow rate Sta. 2+00 - gpm	17.4	17.8	16.7	
Intake rate - gpm	3.0	3.5	3.1	Avg. 3.2

3.2/2.0 = 1.60 gpm per 100 feet final furrow rate.
1.60/3.0 = 0.533 inch per hour final field rate.
0.533 x 1.33 = 0.71 inch per hour average field rate.
0.71 x 6.9 = 4.9 inches average intake depth.

Estimating Rates of Flow

The discussion and examples presented to illustrate procedures for evaluating irrigation water management practices assumed that the rate of flow of the irrigation stream was known. In many cases this is true. If water is delivered from a well the farmer usually will know the approximate discharge. Many irrigation districts and irrigation companies measure delivery flows at the farm headgate. Some farm systems have weirs or other water-measuring devices to measure the flows to specific fields. However, in cases where the rates of flow are not known it may be necessary to rely on estimates. Measurements of some kind usually are needed. Some of the most usable estimating procedures, such as the float method and velocity head rod for open channels and the trajectory method for pipe flow, are discussed in Chapter 3 of this manual and Chapter 9, Section 15, SCS National Engineering Handbook.

SPECIAL PROBLEMS

In evaluating irrigation water management practices it is important that all of the circumstances, conditions and objectives involved be carefully considered. Under some conditions the conservation use of water resources cannot be appraised adequately in terms of a computed field application efficiency. It may be necessary to consider the whole farm or even, in some cases, an entire irrigation project or watershed area. Also, there are conditions under which it is not practicable to apply a needed irrigation without substantial deep percolation or surface runoff losses. Some of the more commonly encountered problems are discussed below.

Irrigation at High Moisture Levels

Sometimes it is necessary to apply irrigation water when only the top few inches of soil are below field capacity. This kind of irrigation may be needed to:

1. Furnish moisture for seed germination.
2. Keep the surface moist to prevent crusting on some soils.
3. Wet the surface to reduce damage to emerging plants by salt accumulations.

Under surface methods of water application these irrigations may be very inefficient. Where only one such irrigation is needed to get a crop established, the low level of efficiency usually can be tolerated. However, the use of sprinklers should be considered where several of these light irrigations are required. Lettuce growers in the Salinas Valley of California, for example, have found that by irrigating with sprinklers until thinning time they can greatly reduce the amount of water needed and at the same time obtain a more uniform crop stand. After thinning time the crop is irrigated by the furrow method. In other areas farmers have found distinct advantages in the use of sprinklers for the establishment of grass and legume crops.

Evaluation studies of these early-season special-purpose irrigations are desirable. However, they usually form a poor basis for appraising the farmer's overall irrigation water management practices since irrigation systems usually are designed for the normal irrigations required after the crops have become established.

Lateral Spread of Water

Where cultivated row crops are irrigated by the furrow method the furrow spacing usually is fixed. On these fields irrigation must be continued until an adequate lateral spread of water has been obtained. On some soils the extended time needed to wet the soil adequately between furrows may result in a low application efficiency. In most cases the entire ground surface need not be wetted ("blacked out"). However, usually the irrigation should be continued until the wetted bulbs from adjacent furrows touch, or nearly touch, at their widest point. Very little lateral spread can be expected after the water is turned off. Most of the moisture movement or soil drainage will be in a vertical direction after the irrigation is completed.

The problem of obtaining adequate lateral spread usually is greatest with crops planted on high ridges or beds. It is especially hard to do where these conditions are combined with steep irrigation grades that limit the depth of flow in the furrows. Under these circumstances improvements often can be obtained by changing the irrigation layout so as to irrigate across the slope. The flatter irrigation grades will permit the use of furrow streams having greater depths of flow and greater wetted perimeters. Sometimes it is even desirable to use level furrows. The increased wetted area will reduce the distance the water has to move laterally and upward into the beds. Sometimes the lateral movement can be speeded by rolling or otherwise compacting the beds. Loose ridges or beds often have many large pore spaces. When the beds are compacted the pore size distribution is improved and capillary movement is accelerated.

Leaching

In some areas extra water may need to be put into the soil to prevent the accumulation of excessive amounts of salts in the crop root zone. This is called leaching. Leaching can be effective only where drainage through the root zone profile is possible.

Water for leaching purposes should be applied in accordance with a planned program. Usually extra water for leaching need not be applied at every irrigation. Generally a satisfactory salt balance can be maintained by leaching applications made during the nonpeak use period. A need for leaching is never an adequate excuse for poor irrigation water management practices. Inefficient and poorly distributed irrigation water applications are more apt to intensify salt problems than to alleviate them. After a soil has been drained and initially leached the amount of excess irrigation water applied to maintain a favorable salt balance should be based on the quality of the water and the salt tolerance of the crops being irrigated. This determination requires detailed analysis and should be made only by those thoroughly familiar with the leaching process.

Overall Water Resource Use

A primary objective of the Soil Conservation Service is the conservation use of water. Conservation use, however, is not always synonymous with high field application efficiency. There are circumstances under which irrigations applied at very low efficiency are not wasteful of water.

For example, suppose a farmer in the upper part of a watershed has a water supply available for diversion that is far in excess of the consumptive needs of his crops. He spreads this water over his fields using large but nonerosive streams so that the lower ends of the irrigation runs will have nearly as much intake opportunity time as the upper ends. He stops irrigating when the water has been applied long enough to refill the crop root zone, but he makes no effort to minimize surface runoff. He merely collects the runoff in waste water ditches and returns it to the stream. His field application efficiencies may average less than 50 percent, but can one say this is not conservation irrigation water management? There is no waste of the water resources. The surface runoff is immediately returned to the stream channel where it is available for diversion by downstream users. There is no soil erosion, and water losses from deep percolation are minimized.

Circumstances such as described above should be fully considered in evaluating a farmer's irrigation water management practices. Always, however, in appraising overall water use one must be sure all of the pertinent factors are taken into account. Water quality, for example, is a factor sometimes overlooked. Irrigation water lost by deep percolation often is recovered in the stream as return flow. Seldom, however, is this water comparable in quality to the original stream supply. Percolating waters usually pick up some salts as they move through the soil profile. Return flows from surface runoff may under some circumstances also be impaired in quality. Water management practices that result in low field application efficiencies, therefore, should be examined critically and thoroughly before they are accepted as meeting conservation objectives.

14. MOISTURE ACCOUNTING METHOD OF SCHEDULING IRRIGATION

USAGE

Moisture accounting is a proven useful method for scheduling irrigations in humid areas by providing a running account of available moisture in the effective root zone. It requires a daily recording of rainfall, estimated evapotranspiration, net irrigation amounts, and moisture balance throughout the growing season of the irrigated crop. Effectiveness of the method depends upon the accuracy with which available moisture holding capacities of the soil, rainfall, net irrigation amounts and evapotranspiration values are determined. The same degree of accuracy should be used in determining each of these factors. Therefore, usage of the method is limited to those areas where conditions permit the obtaining of reliable values. In humid areas occasional rains refill the root zone to field capacity, thereby preventing an accumulation of errors that might affect the accuracy of the method.

Of the factors mentioned above, perhaps the most critical aspect is the determination of daily evapotranspiration. The means for determining evapotranspiration must be reliable, yet relatively simple, to receive acceptance by the average irrigator. This requires a compromise between precise measurement and the practical limitations imposed by field conditions.

In the Northeast United States the relationship of evapotranspiration to daily hours of sunshine and stage of crop growth has been satisfactorily established. Generalized tables are available which provide daily adjustments to evapotranspiration based on observations of sunshine hours. New tables and different adjustment factors or possibly an entirely new kind of estimating procedure will be needed in other areas of the United States.

BASIC PRINCIPLES

This method utilizes two important principles:

1. When an adequate supply of available moisture is present in the effective root zone the rate of consumptive use by a given crop depends primarily on the stage of growth and climatological conditions.

2. When the moisture content of the effective root zone is known at any given time the moisture content at any later time can be computed by crediting moisture gained from effective rainfall or irrigation and subtracting the daily moisture withdrawals during the elapsed time.

CONDITIONS FOR USE

To apply the above principles the following are necessary:

1. Soils with good internal and surface drainage.
2. An adequate irrigation system and water supply.
3. Daily consumptive use values for the crop.
4. Sufficient plant population.
5. Accurate total available moisture values.
6. A knowledge of the effective root zone of the crop.
7. Measurement of effective rainfall and irrigation applications at the site.
8. Occasional soil moisture checks to verify the account. This is especially important during the critical periods of crop growth and for inexperienced users.

EQUIPMENT REQUIRED

1. Wedge-shaped plastic rain gage 2- by 2½-inch minimum top opening.
2. Record book.
3. Means of measuring average application rate of sprinklers or the application amount by surface methods.

INSTALLATION AND READING OF RAIN GAGE

To obtain a measurement of the rainfall in the irrigated area the rain gage should be set on a post located in the field or in an open area adjacent to the field being irrigated. Its distance from nearby obstructions that might affect the catch, such as trees or buildings, should be at least twice the height of the controlling obstruction. The gage should be 3 to 4 feet above ground level with its top at least 3 inches above the top of the post.

The amount of rainfall in the gage should be read at the lowest point of the water surface. The reading should be made as accurately as possible, preferably to the nearest one-hundredth of an inch. After the rainfall amount has been recorded the gage should be emptied and reset in its holder.

USE OF THE MOISTURE BALANCE SHEET FOR SCHEDULING IRRIGATION

1. Record all available pertinent information in the heading. See sample, Table 15-4.

2. Determine the total available moisture-holding capacity of the effective root zone and record it in the heading of the form. Use one of the following sources:

    a. Field testing. This is the most accurate and is done by established field procedures. Field measured values of moisture percentage at field capacity and dry density should be used whenever possible. The moisture percentage at wilting point should be taken from soil characteristic reports covering representative soils or estimated as described later under Moisture Percentage at Wilting Point.

    b. Irrigation guides.

    c. Other publications giving soil characteristics of local soils.

3. Determine the balance when irrigation is to begin. The value frequently used is 50 percent of the total available moisture in the effective root zone. The selected value is one which is suited to site conditions and the operational plan. Irrigation must begin when the soil moisture is at a level that will permit the completion of the irrigation cycle before the available moisture is seriously depleted. Some growers may desire a starting balance that provides for the maintenance of moisture above the 50-percent level. Others may choose a starting balance that permits irrigation applications of a stated amount, i.e., about 1 inch net irrigation each application.

Accounting Procedure

Refer to Table 15-4. Although the example is for a crop of early potatoes, the same procedure applies to other crops and soils. The example is from an account for an entire growing season.

Beginning Moisture Balance

On a date near the normal planting date or start of growth for perennial crops and tree fruits, when the field is at field capacity, enter the total available moisture-holding capacity of the soil in the daily balance column (6) of the Moisture Balance Sheet, Table 15-4.

1. When the soil moisture content is below field capacity at the

Table 15-4 Moisture balance for scheduling irrigation
(sheet 1 of 4)

Month March 1965
Farm I. M. Manager
Soil type Sassafras sl
Crop Early Potatoes Root depth 18 in.
County Sussex
Available Moisture Capacity 2.40 in.
Field 2
Irrigate when balance is 1.40 in.

Date	(1) Days After Transplanting or Emergence	(2) Observed Sunshine Hours	(3) Est. Daily Evapotranspiration (ET) In/Day	(4) Rainfall In.	(5) Net Irrigation Application In.	(6) Daily Balance In.	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward ____				Note: Use ET Table for 90-day growing season.
1							
2							
3							
4							
5				1.26		2.40	Soil at field capacity
6							
7							
8							
9							
10							
11							
12							Planting date
13							
14							
15							
16		11				1.90	Estimated
17		2	0	0.31		2.21	
18		1	0	0.75		2.40	Total 2.96, 0.5 over 2.40
19		10	.03			2.40	
20		6	0	0.36		2.40	
21		11	.03			2.37	Evaporation, soil surface
22		12	.03			2.34	"
23		12	.03			2.31	"
24		12	.03			2.28	Plant emergence
25	1	10	.04	0.08		2.24	Less than 0.2 rain
26	2	2	.04	0.78		2.40	0.5 over FC
27	3	10	.04			2.40	Free water use
28	4	3	.04	0.28		2.40	Free water use
29	5	10	.04			2.36	
30	6	11	.05			2.31	Sprayed
31	7	10	.05			2.26	ET rate change
TOTALS			.45	3.82			

Table 15-4 Moisture balance for scheduling irrigation
(sheet 2 of 4)

Month April 1965

Farm I. M. Manager

County Sussex

Field 2

Soil type Sassafras sl

Crop Early Potatoes Root depth 18 In.

Available Moisture Capacity 2.40 In.

Irrigate when balance is 1.40 In.

Date	(1) Days after Transplanting or Emergence	(2) Observed Sunshine Hours	(3) Est. Daily Evapotranspiration (ET) In/Day	(4) Rainfall In.	(5) Net Irrigation Application In.	(6) Daily Balance In.	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward			2.26	
1	8	8	.05			2.21	
2	9	0	.05	0.54		2.40	FC
3	10	4	.05			2.35	
4	11	11	.06			2.29	
5	12	11	.06			2.23	
6	13	11	.07			2.16	ET rate change
7	14	6	.06	0.40		2.40	FC
8	15	12	.07			2.33	
9	16	0	.06	0.90		2.40	0.5 over FC. Allow 2 days
10	17	6	.06			2.40	Free water use
11	18	12	.07			2.40	Free water use
12	19	12	.09			2.31	Sprayed, cultivated
13	20	12	.09			2.22	
14	21	6	.08			2.14	
15	22	3	.07	0.16		2.07	Less than 0.2 rain
16	23	3	.07	0.25		2.25	
17	24	4	.08			2.17	
18	25	6	.10			2.07	
19	26	3	.08	0.24		2.23	
20	27	10	.10	0.02		2.13	Less than 0.2 rain
21	28	12	.12			2.11	Field moisture check; moisture @ 2.11 WJC
22	29	13	.12			1.99	
23	30	10	.10			1.89	
24	31	8	.12	0.05		1.77	rain less than 0.2
25	32	12	.15			1.62	
26	33	6	.12	0.05		1.50	rain less than 0.2
27	34	5	.12	0.32		1.70	Cultivate
28	35	9	.12	0.07		1.58	
29	36	12	.15			1.43	Laid sprinkler pipe
30	37	13	.17		1.15	2.40	
31							
TOTALS			2.71	3.00	1.15		

Table 15-4 Moisture balance for scheduling irrigation
(sheet 3 of 4)

Month May 1965
Farm I. M. Manager
Soil type Sassafras sl
County Sussex
Crop Early Potatoes Root depth 18 In.
Available Moisture Capacity 2.40 In.
Field 2
Irrigate when balance is 1.40 In.

Date	(1) Days After Transplanting or Emergence	(2) Observed Sunshine Hours	(3) Est. Daily Evapotranspiration (ET) In/Day	(4) Rainfall In.	(5) Net Irrigation Application In.	(6) Daily Balance In.	(7) Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
		Balance Brought Forward				2.40	
1	38	13	.17			2.23	Sprayed
2	39	12	.17			2.06	
3	40	10	.14			1.92	
4	41	10	.14			1.78	
5	42	12	.17			1.61	
6	43	10	.16			1.45	
7	44	13	.20		1.15	2.40	
8	45	12	.20			2.20	Sprayed
9	46	14	.20			2.00	
10	47	12	.20			1.80	
11	48	12	.20			1.60	
12	49	12	.20			1.40	
13	50	10	.17		1.20	2.40	
14	51	10	.17			2.23	
15	52	11	.20			2.03	
16	53	9	.17			1.86	
17	54	12	.20			1.66	
18	55	14	.20			1.46	
19	56	12	.20		1.20	2.40	
20	57	14	.20			2.20	Sprayed
21	58	10	.17			1.85	Field moisture check; balance 1.85 4:00 pm WJC
22	59	14	.20			1.65	
23	60	12	.20			1.45	
24	61	12	.19		1.15	2.40	
25	62	10	.16			2.24	
26	63	10	.16			2.08	Sprayed
27	64	8	.16			1.92	
28	65	4	.16	0.13		1.76	
29	66	0	.13	0.68		2.31	
30	67	0	.12			2.19	
31	68	3	.12			2.07	
	TOTALS		5.43	0.81	4.70		

Table 15-4 Moisture balance for scheduling irrigation
(sheet 4 of 4)

Month June 1965
Farm I. M. Manager
Soil type Sassafras sl
County Sussex
Crop Early Potatoes Root depth 18 In.
Available Moisture Capacity 2.40 In.
Field 2
Irrigate when balance is 1.40 In.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Date	Days After Transplanting or Emergence	Observed Sunshine Hours	Est. Daily Evapotranspiration (ET) In/Day	Rainfall In.	Net Irrigation Application In.	Daily Balance In.	Remarks: (Appearance of plant, height of plant, measured evaporation, etc.)
			Balance Brought Forward			2.07	
1	69	13	.18			1.89	
2	70	10	.15			1.74	
3	71	0	.12	1.27		2.40	
4	72		.15			2.40	Don's graduation-weekend trip
5	73		.14			2.40	ET estimated
6	74		.14			2.26	
7	75	13	.17			2.09	
8	76	8	.14	0.05		1.95	
9	77	8	.14	0.08		1.81	
10	78	10	.14			1.67	
11	79	12	.15			1.52	
12	80	3	.10	0.10		1.42	
13	81	12	.15			1.27	
14	82	12	.15			1.12	
15	83	3	.08	0.10		1.04	Adjusted ET value. AM below 50%
16	84	0	.10	0.75		1.69	
17	85	2	.09	0.14		1.60	
18	86	10	.12			1.48	
19	87	6	.12	0.33		1.69	
20	88	12					Killed tops
21	89						
22	90						
23	91						
24	92			0.01			
25	93			0.10			
26	94						
27	95						
28							
29							
30							Started digging
31							
TOTALS				2.93			

time the moisture balance sheet is started, the available moisture remaining at that time will have to be estimated or measured. If the moisture percentage at field capacity has been previously determined for the field,measurement of present moisture percentage is all that is needed to provide an accurate starting value.

2. If field measurement of moisture percentage at field capacity has not been possible, begin the account with an estimated value. At the first opportunity after adequate rain or irrigation obtain the field capacity moisture percentage and correct the account accordingly.

3. If at the time of plant emergence a week or more has passed since the soil was at field capacity, and tillage and seeding operations have ensued, the moisture balance may be estimated as being about 0.5 inch below the field capacity value.

4. Early season moisture losses prior to plant emergence may be estimated by using an evaporation rate from the soil surface of 0.03 inch per day for the first week after the soil has been wetted to field capacity. An evaporation rate of 0.03 inch per week may be used for the remaining period. For bare or tilled soil conditions during May or later season plantings, when the mean daily temperature is above 63 degrees, evaporation from the top 6 inches of moist soil may be estimated to average 0.1 inch per day for the first 5 days, and 0.05 inch per week thereafter.

5. Moisture losses may be estimated by measuring the depth of the dried surface layer and multiplying this depth by the available water-holding capacity of the soil per inch of depth.

6. When a sod or cover crop is plowed under shortly before the planting date the moisture balance may be considerably less than field capacity. Unless total rainfall between plowing and planting has brought the moisture level to field capacity or above, the moisture content of the soil should be measured at the start of recordkeeping.

Determining End-of-Day Moisture Balance

At the end of the day of moisture accounting:

1. Record the hours of observed daily sunshine in column 2. The hours of sunshine for any day will vary according to cloud cover and the length of day.

2. Estimate evaporation from the soil surface, or following transplanting or plant emergence by selecting from an appropriate table of Estimated values of daily evapotranspiration,such as Table 15-5, the moisture use value for the observed weather condition and the stage of crop growth. Enter this value in column 3. This sample table was developed for annual crops, based on climatic, crop and soil conditions found in Northeast United States.

Table 15-5 Sample - Estimated values of daily evapotranspiration for observed sunshine and crop stage of growth

Growing season 90 days

Crop potatoes

Days after transplanting or emergence	Observed weather		
	Cloudy	Fair	Bright
	Hours of sunshine		
	0-3	4-10	11-15
	In./Day	In./Day	In./Day
0-6	0.04	0.04 1/	0.05
7-12	0.05	0.05	0.06
13-18	0.06	0.06	0.07
19-24	0.07	0.08	0.09
25-30	0.08	0.10	0.12
31-36	0.10	0.12	0.15
37-42	0.11	0.14	0.17
43-48	0.13	0.16	0.20
49-60	0.13	0.17	0.20
61-66	0.13	0.16	0.19
67-72	0.12	0.15	0.18
73-78	0.11	0.14	0.17
79-84	0.10	0.12	0.15
85-90	0.09	0.12	0.14

1/ In case it was impossible to observe weather conditions over a period of one or two days, use the underlined values for that period to bring the daily moisture balance up to date.

3. Should the recordkeeper be away for a day or two, select average values for consumptive use and record in column 3.

4. Record the amount of rainfall in column 4. Amounts should be recorded to nearest 0.01 inch.

5. From the preceding day's balance in column 6 subtract the ET use value in column 3. If there has been rainfall exceeding 0.2 inch, column 4, add this value to the daily moisture balance to obtain the new daily balance. If the total exceeds the value for Available Moisture at field capacity in the root zone, enter in column 6 the Available Moisture which has been determined and recorded in the heading of the form. If the total exceeds the Available Moisture value at field capacity by 0.5 inch or more, continue the full moisture balance value for two succeeding days as shown in the example, Table 15-4. During this 2-day period the plants will be using the free water in the root zone.

6. Continue the daily accounting process until the balance recorded in column 6 approaches the value preselected for irrigation to begin. The daily balance shows the amount of remaining available moisture and gives an indication of the amount of irrigation to be scheduled. The net irrigation to be applied is the difference between the current daily balance prior to the start of irrigation and the available moisture-holding capacity plus the estimated evapotranspiration for that day. The gross application is the required net application divided by the expected application efficiency (expressed as a decimal). Add the net irrigation amount to the daily moisture balance to obtain the new daily balance. If some effective rainfall occurs during the irrigation, this adds to the irrigation applied. As stated under item 5, irrigation plus rainfall should bring the soil to field capacity, but the balance cannot exceed the moisture-holding capacity of the soil.

Continue the same process as outlined above at the end of each day during the growing season until the crop has reached the desired maturity level.

Adjustment Factors

When the daily moisture balance is allowed to drop below 50 percent of the total available moisture value it becomes increasingly difficult for the plants to obtain the moisture they need for vigorous growth. In such cases daily evapotranspiration will be reduced.

If for some reason the crop was not irrigated when the daily moisture balance reached the 50-percent level, ET values from Table 15-6 must be reduced. The actual reduction in ET rates varies with the kind of crop. However, the following factors can be used as a guide for estimating probable daily ET rates. For lowered moisture levels, multiply the value obtained from Table 15-5 by the applicable factor for the existing moisture level.

Moisture level percent	Factor
40-50	0.8
30-40	0.6
20-30	0.2

Irrigation Procedure

If several days are required to irrigate the crop, adjustments in the gross application should be made. The application for each succeeding day should be increased by the day's consumptive use. If more than 3 days are required to complete the irrigation cycle the following method may be used to adjust the application requirements:

1. Divide the number of days required to complete the irrigation into 2- or 3-day intervals.

2. Add 0.3 inch or 0.5 inch, depending on interval, to the net application amount used for the previous interval.

Variations in this procedure may be used to fit individual situations.

15. DIRECT GAS PRESSURE METHOD OF SCHEDULING IRRIGATION

The task of keeping a daily moisture accounting record is regarded as burdensome by some operators. To overcome this objection, a less time-consuming, but equally or more accurate method was developed by G. W. Eley and H. M. Kautz. This method requires only occasional soil moisture checks which, when referred to the Soil Characteristics Sheets (Table 15-6) for the field, gives the irrigator direct information on percentage of available moisture remaining and inches of water needed in the effective root zone depth of the crop.

EQUIPMENT

The equipment consists of a soil volume sampler, a sample drier, and a supply of Field Moisture Check forms and Soil Characteristics Sheets. The Eley Volumeter and a carbide moisture tester are used in this procedure. A tube sampler with an extension handle is convenient for sampling soils for moisture content after bulk densities have been determined.

USE OF THE DIRECT GAS PRESSURE METHOD

This simplified method of irrigation water management eliminates daily recordkeeping and the need for estimating the effect of climatic factors and stage of crop growth on daily consumptive use. It requires no accounting for soil moisture changes due to rainfall or irrigation.

Once Soil Characteristics Sheets have been developed for specific areas in the field, the irrigator needs only to make carbide moisture tests of samples from appropriate depths in the field and refer the gage readings to the Soil Characteristics Sheets. The net inches of water to

be applied to an area is the sum of the values for the soil layers sampled in the effective root zone depth.

It is necessary to have a Soil Characteristics Sheet for each typical soil or control area in the field. One Soil Characteristics Sheet will apply to all crops in the same area by using the appropriate effective root zone depths.

It is expected that the irrigator will be given technical assistance in developing at least his first Soil Characteristics Sheet. In the interest of providing training and reducing the number of samples to be taken, it would be desirable for the technician to assist in developing the Soil Characteristics Sheets to include the root zone depths for all crops to be grown in a particular field or fields.

Sample Problem

The following example outlines the procedure for preparing the Soil Characteristics Sheet. See Table 15-6.

Given:

Soil - Sassafras Sandy Loam

0 - 8"	**Dark brown; Sandy loam; weak, fine granular structure; very friable.**
8 -15"	**Yellowish brown; Sandy loam; structureless to weak, medium subangular blocky structure; friable.**
15 -24"	**Yellowish brown; with some brown sandy loam; weak, fine to medium subangular blocky structure; some very fine roots; some wormholes and wormcasts.**

Irrigated crops - peas, peppers, potatoes, snapbeans

Effective root depths - 12 and 18 inches

Moisture Percentage at Field Capacity

Determine the percent of moisture at field capacity in each soil layer, using a carbide moisture tester and Eley Volumeter:

1. **Dig a hole a little beyond the effective root depths to be considered.**

2. **Record in the heading of the Soil Characteristics Sheet the depth ranges of the different soil layers down to include effective root zone depths of crops to be irrigated. Use additional sheets if necessary.**

3. Take test samples of the different textural layers as shown in Figure 15-4.

4. Weigh a 26-gram sample from the test sample taken from each layer with the Volumeter. Record the volume of soil required to equal 26 grams. Determine the moisture percentage in each weighed sample by means of the carbide moisture tester. The gage reading is the moisture percentage, based on wet weight of the sample.

5. Record the gage reading for each soil layer on the line of the Soil Characteristics Sheet opposite 100 (F.C.). Convert these values to percent of moisture based on dry weight of the sample by means of the carbide moisture tester Conversion Chart (Exhibit 15-6).

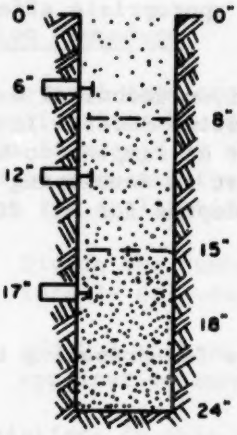


Figure 15-4 Sampling of textural layers

For example:

Soil Layer Inches	Moisture Tester Gage Reading	Percent Moisture Dry Weight of Sample
0-8	16.4	18.9
8-15	15.1	17.1
15-24	15.9	18.2

6. Record the dry weight moisture percentage for each soil layer on the line of the Soil Characteristics Sheet, Table 15-6, opposite 100 (F.C.).

Bulk Density Measurement

Compute the bulk density of the soil in each layer, using the formula:

$$\text{Bulk Density} = \frac{\text{Weight of Sample}}{\text{Volume of Sample} \quad \left(1 + \frac{\text{Percent Moisture, Dry Weight}}{100}\right)}$$

Where:

Weight of samples equal 26 grams.

Volumes of samples equal 14.0, 14.8, and 15.2 cc, respectively. (Obtained while getting moisture percentage at Field Capacity).

Percent moisture, dry weight, equals 18.9, 17.1, and 18.2, respectively.

0-8" layer:

$$\text{Bulk Density} = \frac{26}{(14.0)(1 + \frac{18.9}{100})} = \frac{26}{14\ 0(1.189)} = 1.56 \text{ grams/cc}$$

8-15" layer:

$$\text{Bulk Density} = \frac{26}{(14.8)(1 + \frac{17.1}{100})} = \frac{26}{14.8(1.171)} = 1.50 \text{ grams/cc}$$

15-24" layer:

$$\text{Bulk Density} = \frac{26}{(15.2)(1 + \frac{18.2}{100})} = \frac{26}{15.2(1.182)} = 1.45 \text{ grams/cc}$$

Record these values for the different layers in the spaces for Bulk Density in the heading of the Soil Characteristics Sheet.

Moisture Percentage at Wilting Point

From laboratory or other dependable data, obtain the moisture percentage at 15 atmospheres of soil moisture tension for the type of soil to be irrigated. When this information is not available, use the following fractions to estimate the moisture percentage at the wilting point for each soil layer.

1. For loamy fine sand, use 1/6 of the Field Capacity percentage.
2. For very fine sandy loam, use 1/5 of the Field Capacity percentage.
3. For fine sandy loam, use 1/4 of the Field Capacity percentage.
4. For sand, sandy loam, loamy sand, loam, and silt loam, use 1/3 of the Field Capacity percentage.
5. For silty clay and clay, use 1/2 of the Field Capacity percentage.

Record the values obtained in the spaces for wilting point in the heading of the Soil Characteristics Sheet.

Inches of Available Moisture

Compute the inches of available moisture in each soil layer to the selected effective root depth. Use values recorded in the upper portion of the Soil Characteristics Sheet for each soil layer.

Available Moisture =

$$\text{Available Moisture} = \frac{(\text{Field Capacity-Wilting Percentage})(\text{Bulk Density})(\text{Depth of Soil Layer})}{100 \times 1}$$

0-8" layer:

$$\text{Available Moisture} = \frac{(18.9 - 3.8)(1.56)(8)}{100 \times 1} = 1.89 \text{ inches, use } 1.90$$

8-15" layer:

$$\text{Available Moisture} = \frac{(17.1 - 3.4)(1.50)(7)}{100 \times 1} = 1.44 \text{ inches, use } 1.40$$

15-18" layer:

$$\text{Available Moisture} = \frac{(18.2 - 4.6)(1.45)(3)^{1/}}{100 \times 1} = 0.59 \text{ inch, use } 0.60$$

Total Available Moisture in 18" root depth = 3.90 inches

1/ Note: The 15-24" soil layer is 9 inches thick but in this example the crop roots effectively utilize only 3 inches of this layer.

Net Moisture Requirement at Each Moisture Level

Beginning at the zero Available Moisture Level at the bottom of the Equivalent Moisture Table (Exhibit 15-7) follow horizontally until a number is found that is equal to the inches of available moisture at field capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed Net Water to Apply. Repeat for each soil layer.

Determining Adjustment Percentages

Calculate for each soil layer the adjustment percentage needed to relate percent moisture dry weight to the available moisture level percentage. The adjustment percentage is determined for the range of available moisture levels from 100 percent (field capacity) to zero percent (permanent wilting point).

$$\text{Adjustment Percentage} = \frac{\text{Field Capacity Percent - Wilting Point Percent}}{10}$$

Use percentage values at field capacity and wilting point which have been found and recorded on the Soil Characteristics Sheet.

0-8" layer:

$$\text{Adjustment Percentage} = \frac{18.9 - 3.8}{10} = \frac{15.1}{10} = 1.51$$

8-15" layer:

$$\text{Adjustment Percentage} = \frac{17.1 - 3.4}{10} = \frac{13.7}{10} = 1.37$$

15-18" layer:

$$\text{Adjustment Percentage} = \frac{18.2 - 4.6}{10} = \frac{13.6}{10} = 1.36$$

Dry Weight Moisture Percentages at Each Moisture Level

Insert the field capacity percentage for each soil layer in the Dry Weight Moisture Percent column of the Soil Characteristics Sheet opposite the 100 percent figure in the Available Moisture Level column.

From the Field Capacity percentage for each soil layer subtract the applicable Adjustment Percentage to obtain the relative Dry Weight Moisture Percent for 90 percent Available Moisture Level. Repeat this procedure until the zero percent Available Moisture Level is reached.

For example:

0-8" layer:

100 percent = Field Capacity = 18.90 percent dry weight, record 18.9

90 percent = 18.90 - 1.51 = 17.39 percent dry weight, record 17.4

80 percent = 17.39 - 1.51 = 15.88 percent dry weight, record 15.9

Complete the other columns for other soils layers, similarly.

Gage Readings for Each Dry Weight Moisture Percentage

Locate in the body of the carbide moisture tester Conversion Chart (Exhibit 15-6) the correct dry weight percentage for each level of moisture and find its corresponding gage reading. Record this value for each level of soil moisture in the Moisture Tester Gage Reading column on the Soil Characteristics Sheet.

This completes the development of the Soil Characteristics Sheet for crops to an 18-inch root zone depth and it is now ready for field use.

Checking and Recording Soil Moisture

With the Soil Characteristics Sheet prepared, the irrigator needs only to check the soil moisture to determine when and how much water to apply. As the need for irrigation approaches, as indicated by soil moisture estimates, the irrigator simply makes a moisture check with the carbide moisture tester at the typical field locations. For many soils a tube sampler similar to the Oakfield Probe is useful for this check.

Assume the crop is potatoes with an 18-inch root depth. The field information obtained is recorded in the first four columns of the Field

Moisture Check Sheet, as shown on Table 15-7. This includes the date of sampling, the soil layers sampled, the depths at which the samples were taken, and the carbide moisture tester gage reading for each sample.

Use of the Soil Characteristics Sheet

The irrigator then turns to the Soil Characteristics Sheet and finds the Gage Reading for each soil layer that corresponds to the gage readings just recorded in column 4 of the Field Moisture Check Sheet. Reading horizontally to the left on the Soil Characteristics Sheet he will find the comparable Available Moisture Level and record this information in column 5 of the Field Moisture Check Sheet. Then reading horizontally to the right he will find the comparable Net Water to Apply and record it in column 6. Some simple interpolations may be necessary if the gage readings obtained in the field do not correspond exactly to those shown on the Soil Characteristics Sheet. See the example shown in Table 15-6 and the interpolated values in column 6 of the Field Moisture Check Sheet.

Again referring to the Field Moisture Check Sheet, the sum of the figures in column 6 for each sampling location will be the net inches of water to apply to bring the effective root zone depth up to field capacity. The percentages of available moisture level recorded in column 5 will indicate whether or not the crop is ready for irrigation.

In the event the crop does not need irrigating at this time, the irrigator can repeat the moisture check in two or three days and record the date and information in the Field Moisture Check Sheet. By noting the amount that the available moisture level has declined during the period between the two recorded dates, he can closely approximate when he should make another check or start irrigating.

If the crop were one with a 12-inch root zone depth, moisture check samples would normally be taken at about the 5- and 10-inch depths. The required net irrigation needed at time of sampling would be the sum of the net water needed in the 0- to 8-inch layer plus a proportional amount of the value indicated for the 8- to 15-inch layer.

For example:

Soil layer inches	Net water to apply inches	
0-8		= 1.0
8-12	$\frac{4}{7}$ (0.5)	= 0.3
	Total	1.3

Table 15-6 Soil characteristics sheet for irrigation water management

Field 3 Crop potatoes

Farm Sample

Location Upper end

Available Moisture Level 1/ (Applies to all layers)	0 to 8 In. Soil Layer			8 to 15 In. Soil Layer			15 to 18 In. Soil Layer		
	Field Capacity 2/ 18.9 %	Wilting Point 3/ 3.8 %	Bulk Density 4/ 1.56	Field Capacity 17.1 %	Wilting Point 3.4 %	Bulk Density 1.50	Field Capacity 18.2 %	Wilting Point 4.6 %	Bulk Density 1.45
(Percent)	Dry Weight Moisture Percent	Speedy Tester Gage Reading 5/	Net Water To Apply Inches 6/	Dry Weight Moisture Percent	Speedy Tester Gage Reading	Net Water To Apply Inches	Dry Weight Moisture Percent	Speedy Tester Gage Reading	Net Water To Apply Inches
100 (F.C.)	18.9	16.4	0	17.1	15.1	0	18.2	15.9	0
90	17.4	15.3	.19	15.7	14.1	.14	16.8	14.9	.06
80	15.9	14.2	.38	14.4	13.1	.28	15.5	13.9	.12
70 7/	14.4	13.1	.57	13.0	12.0	.42	14.1	12.8	.18
60 7/	12.9	11.9	.76	11.6	10.8	.56	12.9	11.8	.24
50 7/	11.3	10.6	.95	10.3	9.7	.70	11.4	10.7	.30
40	9.8	9.3	1.14	8.9	8.5	.84	10.0	9.5	.36
30	8.3	7.9	1.33	7.5	7.2	.98	8.7	8.3	.42
20	6.8	6.5	1.52	6.1	5.9	1.12	7.3	7.0	.48
10	5.3	5.2	1.71	4.8	4.8	1.26	6.0	5.8	.54
0 (W.P.)	3.8	3.8	1.90	3.4	3.4	1.40	4.6	4.6	.60

1/ The ratio of the inches of remaining available moisture to the field capacity in a specific soil layer, expressed as a percent. (100 percent equals Field Capacity; zero percent equals Permanent Wilting Point.

2/ A field measurement of amount of water retained in a well-drained soil, 1 to 4 days after a thorough wetting by rainfall or irrigation, expressed as a percent of the dry weight of the soil.

3/ The moisture content, expressed as a percent of the dry weight of the soil, at which plants can no longer extract moisture.

4/ The ratio of dry weight of the sample in grams to its volume in cubic centimeters.

5/ The moisture content of a specific soil sample, expressed as a percent of the wet weight of the soil.

6/ Net inches of water to bring the soil layer to field capacity. When different soil layers are utilized by a crop, the total net application is the sum of the net amounts required for each soil layer.

7/ Desirable time to start irrigation, depending on the crop and number of days required to irrigate the crop.

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Table 15-7 Field moisture check sheet for determining when to irrigate and how much water to apply

(1) Date (Month & Day)	(2) Soil Layer (Inches)	(3) Sample Depth (Inches)	(4) Gage Reading (Percent)	(5) Available Moisture Level (Percent)	(6) Net Water To Apply (Inches)	Notes
June 11	0 - 8	6	10.6	50	1.0	18" depth for
	8 - 15	12	11.4	65	0.5	potatoes
	15 - 18	16	14.4	85	0.1	Upper end
					1.6	field 3

SAMPLE

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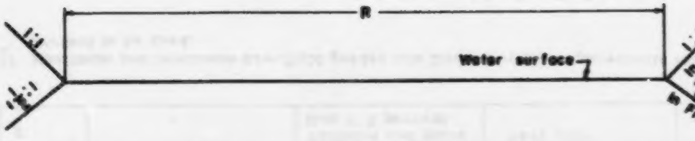
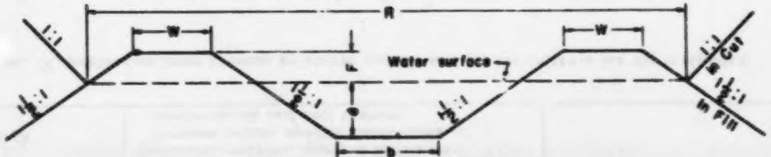


LATERAL BED BEFORE DITCH IS PULLED



FINISHED DITCH SECTION

Ditch No.	b	d	F	W	R	A	r	s = 0.0005				s = 0.001				s = 0.002				s = 0.003			
								n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04	
								V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
	feet	feet	feet	feet	feet	sq.ft.	feet	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs
612	0.5	1.0	0.5	1.00	8.5	2.00	0.48	0.69	1.4	0.51	1.0	0.97	1.9	0.73	1.5	1.37	2.7	1.03	2.1	1.68	3.4	1.26	2.5
1212	1.0	1.0	0.5	1.50	10.0	2.50	0.54	0.73	1.8	0.55	1.4	1.05	2.6	0.78	2.0	1.47	3.7	1.10	2.8	1.79	4.5	1.35	3.4
1812	1.5	1.0	0.5	2.00	11.5	3.00	0.59	0.78	2.3	0.58	1.7	1.10	3.3	0.83	2.5	1.56	4.7	1.17	3.5	1.91	5.7	1.43	4.3
2412	2.0	1.0	0.5	2.50	13.0	3.50	0.62	0.81	2.8	0.60	2.1	1.13	4.0	0.86	3.0	1.61	5.6	1.21	4.2	1.97	6.9	1.48	5.2
1214	1.0	1.2	0.7	1.25	11.3	3.36	0.63	0.81	2.7	0.61	2.0	1.15	3.9	0.87	2.9	1.63	5.5	1.22	4.1	1.99	6.7	1.50	5.0
1814	1.5	1.2	0.7	1.50	12.3	3.96	0.68	0.86	3.4	0.64	2.5	1.21	4.8	0.91	3.6	1.71	6.8	1.28	5.1	2.09	8.3	1.57	6.2
2414	2.0	1.2	0.7	2.00	13.8	4.56	0.72	0.89	4.1	0.67	3.1	1.25	5.7	0.94	4.3	1.78	8.1	1.33	6.1	2.18	9.9	1.63	7.4
1816	1.5	1.33	0.77	1.75	13.6	4.65	0.74	0.90	4.2	0.68	3.2	1.28	6.0	0.96	4.5	1.81	8.4	1.36	6.3	2.22	10.3	1.66	7.7
2416	2.0	1.33	0.77	2.00	14.6	5.31	0.78	0.94	4.9	0.71	3.8	1.33	7.1	0.99	5.3	1.88	10.0	1.41	7.5	2.30	12.3	1.72	9.2
2418	2.0	1:5	1.0	1.50	15.5	6.38	0.86	1.00	6.4	0.75	4.8	1.42	9.1	1.06	6.8	2.00	12.8	1.50	9.6	2.45	15.6	1.83	11.7
3618	3.0	1.5	1.0	2.00	17.5	7.88	0.94	1.06	8.4	0.80	6.3	1.50	11.8	1.12	8.8	2.13	16.8	1.59	12.5	2.60	20.5	1.95	15.4
2421	2.0	1.75	1.1	1.75	17.4	8.10	0.98	1.09	8.8	0.82	6.6	1.55	12.6	1.15	9.3	2.19	17.7	1.64	13.3	2.67	21.6	2.00	16.2
3621	3.0	1.75	1.1	2.50	19.9	9.85	1.06	1.15	11.3	0.86	8.5	1.63	16.1	1.22	12.0	2.30	22.7	1.73	17.0	2.82	27.8	2.11	20.8
4821	4.0	1.75	1.1	3.00	21.9	11.60	1.13	1.20	13.9	0.90	10.4	1.70	19.7	1.27	14.7	2.40	27.8	1.80	20.9	2.94	34.1	2.21	25.6
3624	3.0	2.0	1.3	2.25	21.3	12.00	1.18	1.24	14.9	0.93	11.2	1.75	21.0	1.31	15.7	2.47	29.6	1.86	22.3	3.03	36.4	2.27	27.2
4824	4.0	2.0	1.3	3.00	23.8	14.00	1.25	1.28	17.9	0.96	13.4	1.82	25.5	1.36	19.0	2.57	36.0	1.93	27.0	3.15	44.1	2.36	33.0

A: cross sectional area in square feet.
r: hydraulic radius in feet.
n: coefficient of roughness.
Use n: 0.03 for bare ground.
Use n: 0.04 for grassed ditch bottom.

s: slope in feet per foot.
V: velocity in feet per second.
Q: capacity of ditch in cubic feet per second.

Exhibit 15-1 Irrigation ditch sections with required lateral beds

Class	Irrigation slope 1/	Cross slope	Possible irrigation water efficiencies	Irrigation operation labor requirement	Method limitations	Leveling requirement
A_1	Uniform but not more than 0.05 percent	None	High	Very low	None	None
A_2	Uniform				Length of level borders is restricted.	
B_1		Uniform but not more than 0.3 percent			Length of level borders restricted. Border widths are restricted.	Leveling desirable to increase length or width of level borders.
B_2		Variable but not more than 0.3 percent		Low		
B_3		Either uniform or variable and more than 0.3 percent but not more than 0.5 percent		Moderately low	Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	Leveling desirable to reduce labor requirement.
C_1	Fairly uniform - (When slopes are over 0.5 percent, convex slopes have maximum grades not over twice minimum; concave slopes have maximum grade not over 1 1/2 times minimum. Undulating slopes not permissible.)	Uniform or variable but not more than 0.3 percent	Good		Level borders not permissible. Border widths are restricted.	Leveling desirable to reduce labor requirement and improve irrigation efficiencies.
C_2		Uniform or variable but not more than 0.5 percent			Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_3	Either uniform or fairly uniform as defined above	Either uniform or variable and more than 0.5 percent		Moderate to high	Applicable only for contour ditches or to cross slope or contour furrow irrigation within special limitations of furrow depth and soil texture.	
D_1	Variable but without level reaches or reverse grades	Variable but not more than 0.3 percent	Poor	Moderate	Border widths are restricted. Level borders or corrugations not permissible.	Leveling required for conservation irrigation.
D_2		Variable but not more than 0.5 percent		High	Border widths are very restricted. Level borders or corrugations not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils.	
E		Variable and more than 0.5 percent	Very poor	Very high	Applicable only for contour ditches or furrows within special limitations of furrow depth and soil texture.	

1/ Maximum and minimum downfield grades are limited by (1) requirements for drainage, (2) protection from erosion by storm runoff, and (3) the criteria for the irrigation method to be used.

Exhibit 15-2 Relief classes for surface irrigated land

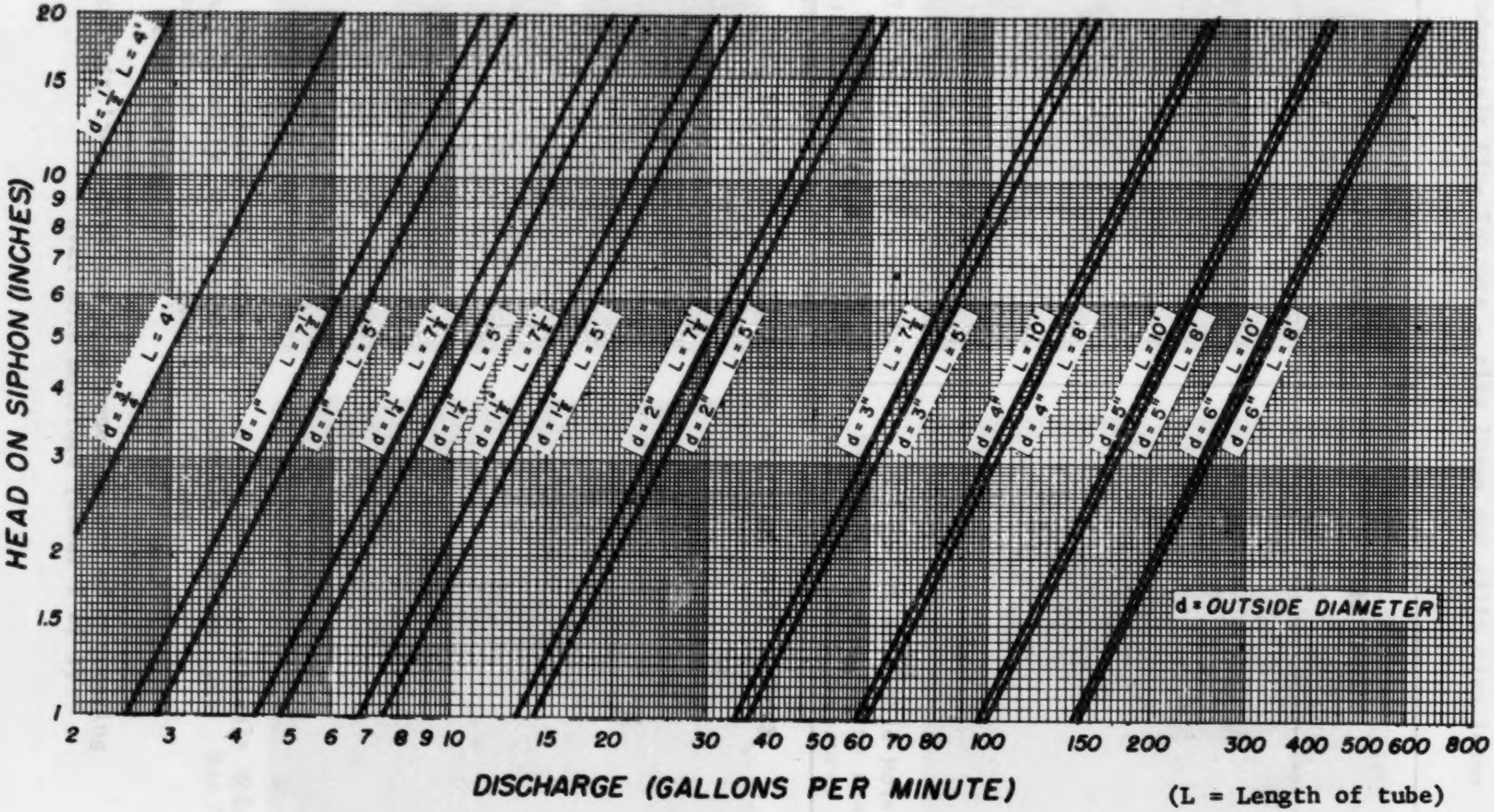
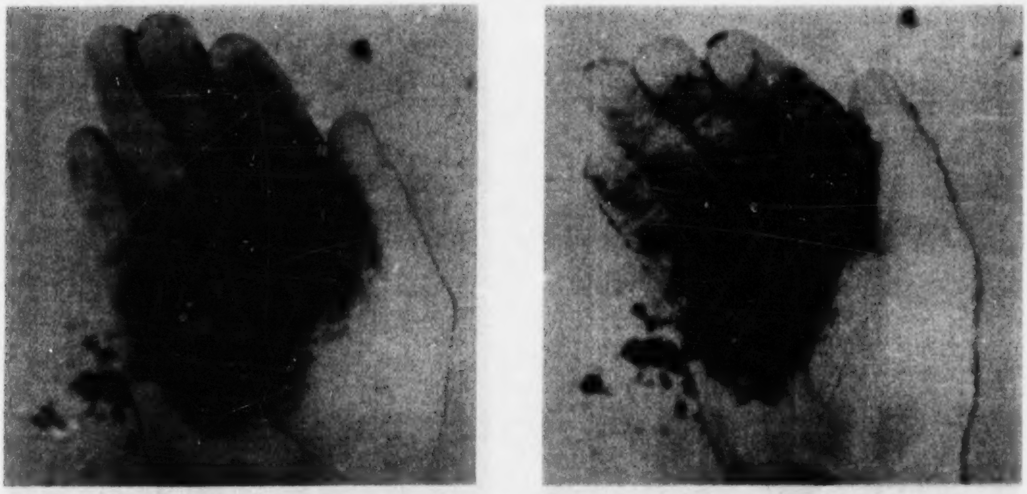


Exhibit 15-3 Discharge of aluminum siphon tubes at various heads

Number of Outlets	Multiple Outlet Factor
5	0.44
10	0.39
15	0.37
20	0.36
30	0.35
50	0.34
100	0.34
∞	0.33

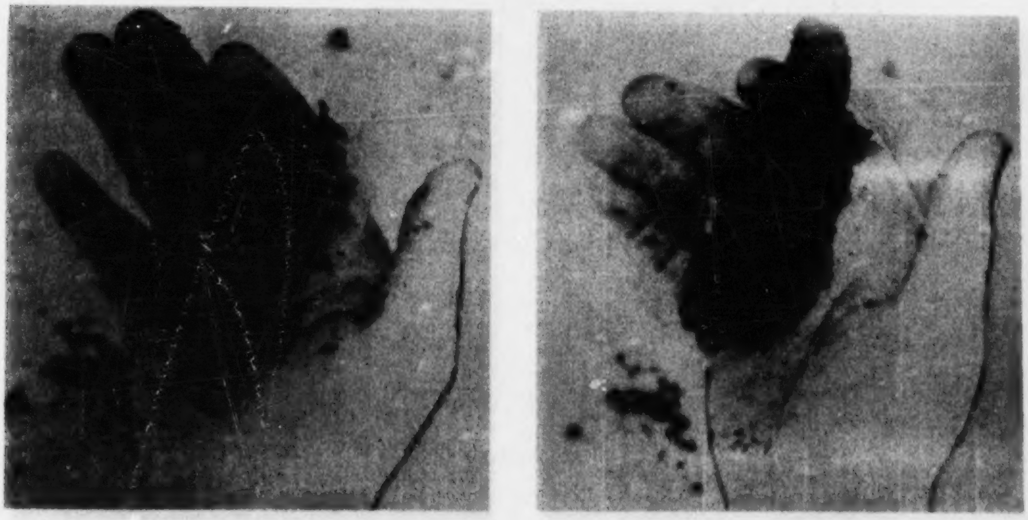
Exhibit 15-4 Multiple outlet factor for gated pipe

Moderately Fine Texture - clay loams and silty clay loams



-- 0 to 25% Available Moisture --
Crumbles readily, will hold together but "balls" with difficulty and breaks easily.

-- 25 to 50% Available Moisture --
Does not crumble, forms readily, will "ball" with pressure.



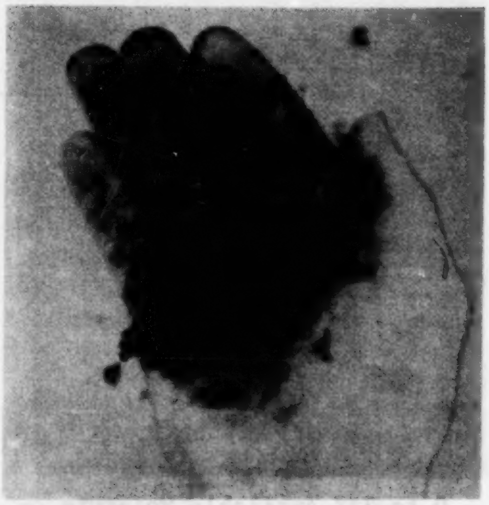
-- 50 to 75% Available Moisture --
Forms "ball" readily, will "ribbon" out between thumb and forefinger. Somewhat slick feeling.

-- 75 to 100% Available Moisture --
Easily "ribbons" out. Has "slick" feeling.

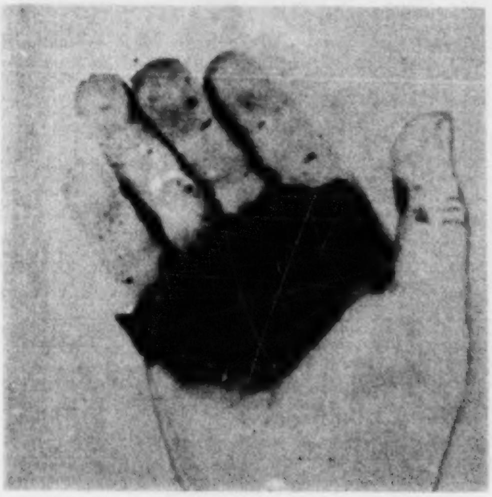
Exhibit 15-5 Feel and appearance method of estimating available moisture (sheet 1 of 3)

Medium Texture - loams and silt loams

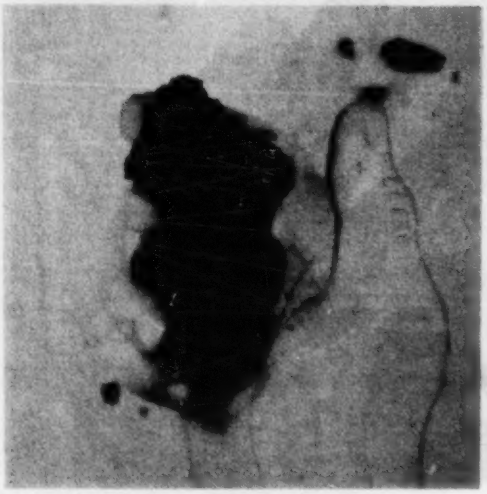
-- 0 to 25% Available Moisture -- Crumbles easily, tends to hold together from hand pressure.



-- 25 to 50% Available Moisture -- Somewhat crumbly, will hold together in hand with pressure.



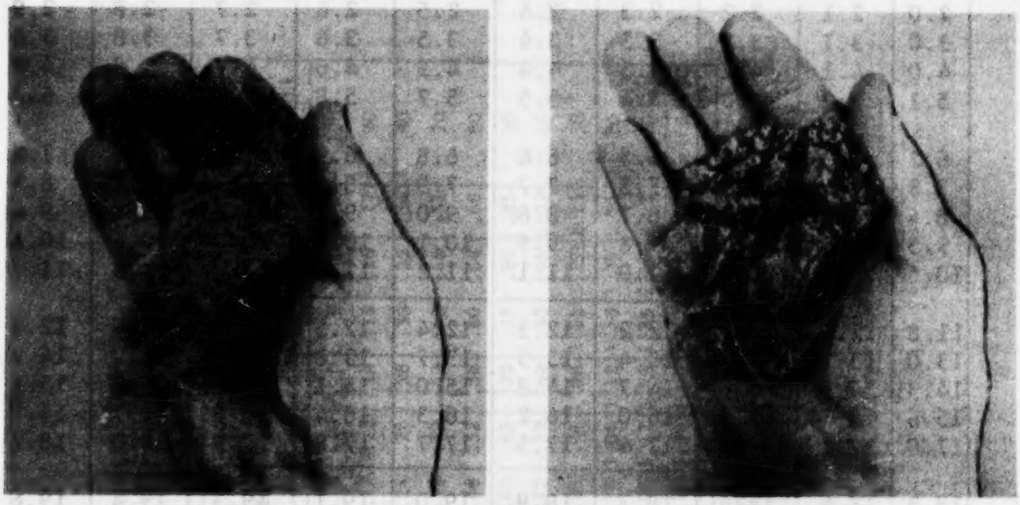
-- 50 to 75% Available Moisture -- Forms "ball" readily, will "slick" slightly with pressure.



-- 75 to 100% Available Moisture -- Forms "ball" easily, fairly friable, "slicks" readily.

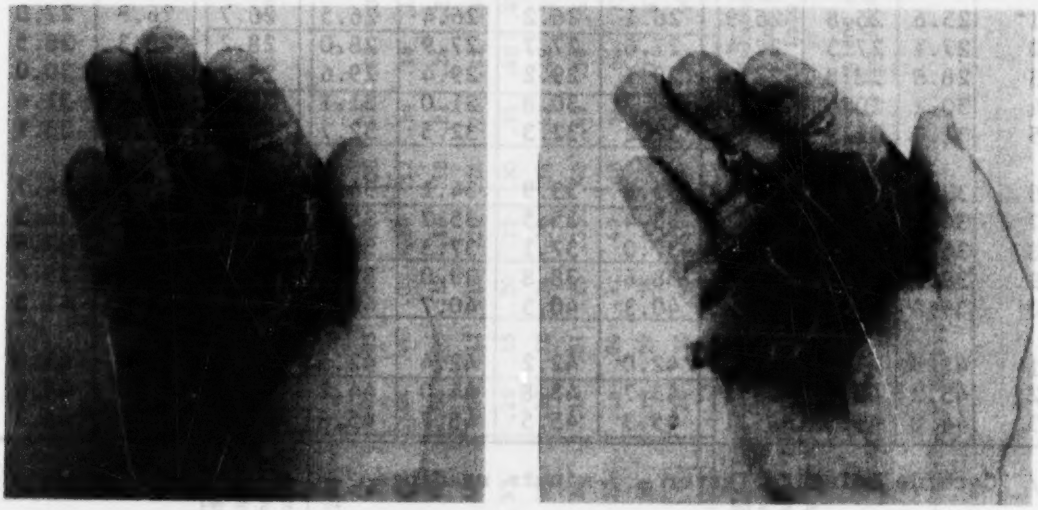
Exhibit 15-5 Feel and appearance method of estimating available moisture (sheet 2 of 3)

Coarse Texture - sandy loams and loamy sands



-- 0 to 25% Available Moisture --
Dry, loose, flows through fingers.

-- 25 to 50% Available Moisture --
Looks dry, will not form ball with pressure.



-- 50 to 75% Available Moisture --
Will form loose ball under pressure, will not hold together even with easy handling.

-- 75 to 100% Available Moisture --
Forms weak ball, breaks easily, will not "slick".

Exhibit 15-5 Feel and appearance method of estimating available moisture (sheet 3 of 3)

Gage Read.1/	Oven Dry Moisture - Percent									
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
2	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
4	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
5	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.8	6.9	7.0	7.1	7.2
7	7.3	7.4	7.5	7.6	7.7	7.9	8.0	8.1	8.2	8.3
8	8.4	8.5	8.6	8.7	8.8	9.0	9.1	9.2	9.3	9.4
9	9.5	9.6	9.7	9.8	9.9	10.1	10.2	10.3	10.4	10.5
10	10.6	10.7	10.8	11.0	11.1	11.2	11.3	11.4	11.6	11.7
11	11.8	11.9	12.0	12.2	12.3	12.4	12.5	12.6	12.8	12.9
12	13.0	13.1	13.3	13.4	13.5	13.7	13.8	13.9	14.0	14.2
13	14.3	14.4	14.6	14.7	14.8	15.0	15.1	15.2	15.3	15.5
14	15.6	15.7	15.9	16.0	16.2	16.3	16.4	16.6	16.7	16.9
15	17.0	17.1	17.3	17.4	17.5	17.7	17.8	17.9	18.0	18.2
16	18.3	18.4	18.6	18.7	18.9	19.0	19.1	19.3	19.4	19.6
17	19.7	19.8	20.0	20.1	20.3	20.4	20.5	20.7	20.8	21.0
18	21.1	21.3	21.4	21,6	21.7	21.9	22.0	22.2	22.3	22.5
19	22.6	22.8	22.9	23.1	23.2	23.4	23.5	23.7	23.8	24.0
20	24.1	24.3	24.4	24.6	24.7	24.9	25.0	25.2	25.3	25.5
21	25.6	25.8	25.9	26.1	26.2	26.4	26.5	26.7	26.8	27.0
22	27.1	27.3	27.4	27.6	27.7	27.9	28.0	28.2	28.3	28.5
23	28.6	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.0
24	30.2	30.4	30.5	30.7	30.8	31.0	31.1	31.3	31.4	31.6
25	31.7	31.9	32.0	32.2	32.3	32.5	32.7	32.8	33.0	33.1
26	33.3	33.5	33.6	33.8	33.9	34.1	34.3	34.4	34.6	34.7
27	34.9	35.1	35.2	35.4	35.5	35.7	35.9	36.0	36.2	36.3
28	36.5	36.7	36.8	37.0	37.1	37.3	37.5	37.6	37.8	37.9
29	38.1	38.3	38.4	38.6	38.8	39.0	39.1	39.3	39.5	39.6
30	39.8	40.0	40.1	40.3	40.5	40.7	40.8	41.0	41.2	41.3
31	41.5	41.7	41.8	42.0	42.2	42.4	42.5	42.7	42.9	43.0
32	43.2	43.4.	43.5	43.7	43.8	44.0	44.2	44.3	44.5	44.6
33	44.8	45.0	45.1	45.3	45.5	45.7	45.8	46.0	46.2	46.3

1/ Carbide Moisture Tester - 3-minute readings

Exhibit 15-6 Carbide moisture tester conversion chart

Available Moisture Level (Percent)	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Available Moisture Level (Percent)
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
90	.02	.03	.04	.05	.06	.07	.08	.09	.10	.11	.12	.13	.14	.15	.16	.17	90
80	.04	.06	.08	.10	.12	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	80
70	.06	.09	.12	.15	.18	.21	.24	.27	.30	.33	.36	.39	.42	.45	.48	.51	70
60	.08	.12	.16	.20	.24	.28	.32	.36	.40	.44	.48	.52	.56	.60	.64	.68	60
50	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	50
40	.12	.18	.24	.30	.36	.42	.48	.54	.60	.66	.72	.78	.84	.90	.96	1.02	40
30	.14	.21	.28	.35	.42	.49	.56	.63	.70	.77	.84	.91	.98	1.05	1.12	1.19	30
20	.16	.24	.32	.40	.48	.56	.64	.72	.80	.88	.96	1.04	1.12	1.20	1.28	1.36	20
10	.18	.27	.36	.45	.54	.63	.72	.81	.90	.99	1.08	1.17	1.26	1.35	1.44	1.53	10
0	.20	.30	.40	.50	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	0

INSTRUCTIONS: Beginning at zero Available Moisture Level at bottom of table, follow this line horizontally until a number is found that equals the inches of Available Moisture at Field Capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed Net Water to Apply.

Exhibit 15-7 Equivalent moisture table for relating available moisture level to net inches of water to apply (sheet 1 of 3)

USDA-SCS-Upper Darby, Pa. 6-65

Available Moisture Level (Percent)	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Available Moisture Level (Percent)
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
90	.18	.19	.20	.21	.22	.23	.24	.25	.26	.27	.28	.29	.30	.31	.32	.33	90
80	.36	.38	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	80
70	.54	.57	.60	.63	.66	.69	.72	.75	.78	.81	.84	.87	.90	.93	.96	.99	70
60	.72	.76	.80	.84	.88	.92	.96	1.00	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	60
50	.90	.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	50
40	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.50	1.56	1.62	1.68	1.74	1.80	1.86	1.92	1.98	40
30	1.26	1.33	1.40	1.47	1.54	1.61	1.68	1.75	1.82	1.89	1.96	2.03	2.10	2.17	2.24	2.31	30
20	1.44	1.52	1.60	1.68	1.76	1.84	1.92	2.00	2.08	2.16	2.24	2.32	2.40	2.48	2.56	2.64	20
10	1.62	1.71	1.80	1.89	1.98	2.07	2.16	2.25	2.34	2.43	2.52	2.61	2.70	2.79	2.88	2.97	10
0	1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10	3.20	3.30	0

INSTRUCTIONS: Beginning at zero Available Moisture Level at bottom of table, follow this line horizontally until a number is found that equals the inches of Available Moisture at Field Capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed Net Water to Apply.

Exhibit 15-7 Equivalent moisture table for relating available moisture level to net inches of water to apply (sheet 2 of 3)

USDA-SCS-Upper Darby, Pa. 6-65

Available Moisture Level (Percent)	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	Available Moisture Level (Percent)
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
90	.34	.35	.36	.37	.38	.39	.40	.41	.42	.43	.44	.45	.46	.47	.48	.49	.50	90
80	.68	.70	.72	.74	.76	.78	.80	.82	.84	.86	.88	.90	.92	.94	.96	.98	1.00	80
70	1.02	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	70
60	1.36	1.40	1.44	1.48	1.52	1.56	1.60	1.64	1.68	1.72	1.76	1.80	1.84	1.88	1.92	1.96	2.00	60
50	1.70	1.75	1.80	1.85	1.90	1.95	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50	50
40	2.04	2.10	2.16	2.22	2.28	2.34	2.40	2.46	2.52	2.58	2.64	2.70	2.76	2.82	2.88	2.94	3.00	40
30	2.38	2.45	2.52	2.59	2.66	2.73	2.80	2.87	2.94	3.01	3.08	3.15	3.22	3.29	3.36	3.43	3.50	30
20	2.72	2.80	2.88	2.96	3.04	3.12	3.20	3.28	3.36	3.44	3.52	3.60	3.68	3.76	3.84	3.92	4.00	20
10	3.06	3.15	3.24	3.33	3.42	3.51	3.60	3.69	3.78	3.87	3.96	4.05	4.14	4.23	4.32	4.41	4.50	10
0	3.40	3.50	3.60	3.70	3.80	3.90	4.00	4.10	4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00	0

INSTRUCTIONS: Beginning at zero Available Moisture Level at bottom of table, follow this line horizontally until a number is found that equals the inches of Available Moisture at Field Capacity for the soil layer. Copy this column of figures into the Soil Characteristics Sheet column headed Net Water to Apply.

Exhibit 15-7 Equivalent moisture table for relating
available moisture level to net inches of water to apply (sheet 3 of 3)

ENGINEERING FIELD MANUAL

CHAPTER 16. STREAMBANK PROTECTION

Compiled by: Harold M. Kautz, Agricultural Engineer, SCS, Upper Darby, Pa.

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ENGINEERING FIELD MANUAL

CHAPTER 16. STREAMBANK PROTECTION

1. GENERAL

DEFINITIONS

The technical guidance provided herein is limited to clearing and snagging and streambank protection measures of simple design. These practices are defined as follows:

Clearing and Snagging

Removing trees, snags, drifts, sediment bars, or other obstructions within the channel to improve flow conditions in the stream channel.

Streambank Protection

Stabilizing and protecting banks of streams or excavated channels against scour and erosion by vegetative or structural means alone or in combination. This does not include protection of lake fronts or streambanks in tidal areas.

2. STREAMBANK PROTECTION CONCEPTS

CAUSES OF STREAMBANK EROSION

The principal causes of streambank erosion may be classed as geologic, climatic, or hydraulic although there may be a very close relationship between them.

Geologic

The soil materials through which the stream channel has cut is a major factor in streambank erosion. Many heavy soils tend to shear in a vertical plane when the base has become saturated or undercut. Likewise, these soils may develop deep dry-weather cracks which accelerate the sloughing of large sections of the streambank during higher than normal flows.

Sandy soils, with their low cohesion properties, are not resistant to tractive forces created by normal flood flows and therefore erode easily.

Flows against gravelly or cobbly soils exert a sorting action which tends to leave the channel bottom armored or covered with cobbles as the finer particles are carried downstream. Although the channel bottom may thus become highly stable, the sorting action of the water flowing against the banks continues and the channel becomes wider. Channels in soil with a solid rock bottom react to flood flows much the same as those which have developed an armored bottom.

Climatic

Storms that create flood flows of long duration are generally more damaging than storms that produce short duration flood flows. This is especially true in areas where the latter type of storms occurs during the season of the year when the vegetative cover on the streambanks is most effective. Flood flows of long duration are more damaging due to the increased time during which the erosive forces act against the channel materials; and the greater saturation of the banks, which may cause them to slough when the flood flow recedes.

In the northern portion of the country the combination of high rates of runoff from frozen ground and floating ice may be highly damaging to the stability of the channel. Ice drifts frequently gouge out existing protective vegetation, or they may lodge in trees or other obstructions and divert currents from their normal course. They also cause weakly-rooted or leaning trees along the bank to fall into the channel, and, by complete blockage of the channel at restricted points, cause detrimental deposits of sediment or bedload material. Where ice is a problem, it is desirable to do sufficient clearing and snagging of the flowage area to permit free passage of the floating ice.

Hydraulic

In general, the erosive and transporting powers of streamflow increase with increases in velocity, turbulence, depth of flow, and gradient of the channel. The ability of streamflow to detach and move soil materials varies inversely with the amount of sediment the stream is carrying. For example, a streamflow that is carrying its maximum debris load, including both suspended and bedload materials, can travel at a higher velocity without accumulating scoured material than a stream which is carrying less than its full capacity debris load.

If the debris load of the stream will be reduced by land treatment and bank protective measures, or if the hydraulics of the channel can be improved by clearing, snagging or resectioning, the effect of these items on bank stability should be considered in determining the remaining needed bank protection measures.

ECONOMIC ASPECTS

Because of the high cost of installing and maintaining streambank protection measures, they normally should be limited to the protection of valuable farmland or other improvements or to reduce the damaging sediment load of a stream. The economic soundness of any project should be estimated at the very outset. Benefits may be from reduction of flood hazard, the prevention or reduction of damaging sediment deposits, reclamation of waste areas made possible by stabilizing the stream location, and by preventing loss of land due to streambank erosion. To these may be added moderate values for intangible social benefits. It will be desirable to request the assistance of the State office if the economic analysis is beyond the training or experience of the work unit staff.

LEGAL ASPECTS

The centerline of a stream frequently is the property boundary between adjacent farms. Any proposed relocation of such a stream needs to be approved by the property owners involved. Protective measures which would cause flooding or increased flooding on an adjoining property should not be installed until all necessary flowage rights have been obtained.

TYPES OF BANK PROTECTION

There are two general types of bank protection:

1. Those which retard flow along the bank and thereby promote deposition.

2. Those which, through some form of bank cover, protect the bank from direct erosion and scouring.

Permeable groins and revetments constructed of piling, rock, tetrahedrons, concrete, trees or other materials are examples of protection which will cause deposition. Groins may be designed to deflect the current away from the bank. Revetments are placed on or parallel to the bank. Both are designed to reduce the velocity of flow adjacent to the bank so that erosion will be halted.

Living vegetation, brush matting, rock riprap, concrete slabs and asphalt lining are examples of revetment or protective bank cover. The type of protection needed for a specific case is determined largely by the characteristics of the stream.

Jetties are not considered to be within the scope of this manual since they can greatly influence the flow and regime of streams. The design of jetties should be done by an experienced professional engineer.

INVESTIGATIONS

The behavior of streams at or near flood stage is often unpredictable without detailed study. Appropriate engineering assistance is required on large streams and on small streams with complex problems.

Before treatment of any streambank is started, several things should be considered:

1. Size of watershed draining into the stream.
2. Expected runoff and flood peaks.
3. Expected duration of flood flows.
4. Soil materials at the site.
5. Size and shape of existing channel.
6. Nature of flow in the stream - continuous or intermittent.
7. Climatic conditions of the area.
8. Degree of protection required.
9. Expected debris load carried by the stream.
10. Causes of existing meandering and erosion. Included among them may be:
    a. Fallen trees deflecting the water from its normal direction of flow.
    b. Trees or brush growing on the inside of a curve deflecting water against the cutting bank.
    c. Water from a waterway or smaller stream entering the channel and depositing sediment, thus deflecting the water against the cutting bank.
    d. Bedload drifts.
    e. Ice drifts.
    f. Damage to banks by livestock.

PLANNING

Planning should include:

1. Determining the cause, nature, and extent of the problem.
2. Consideration of the effect of localized protection on the future behavior of the stream.
3. Analysis of the types of construction that might be used.

4. Design and specifications for the selected protective measures.

5. Cost and economic evaluation of the project.

6. Instructions for applying the measures.

All work on a stream involving more than one job or ownership should be planned together so the flow relationships between jobs can be established.

Minor protective measures may be applied by individuals or small groups of farmers without additional labor or heavy equipment. However, the possible need for these items, as well as the construction materials, should be considered when planning the protective measures.

Full consideration should be given to the need for watershed treatment. The reduction of runoff and soil loss from the watershed by means of sound land treatment measures normally will make the streambank protection problem less severe.

DESIGN

Design Frequency

Maximum floods are rarely used in design. The design in agricultural areas usually should be based on the 10-year frequency flood, but the protective measures should be able to withstand greater floods without serious damage. In other areas the design frequency should be in line with the value or safety of the property or improvements being protected.

Design Velocities

Where the flow entering the section to be protected carries only silt and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on material of the smallest size occurring in any appreciable quantity in the streambed material. The minimum velocity should not be less than that required to transport the suspended material.

Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

In calculating these velocities it is important that the "n" values be selected with care.

Channel Changes

Changes in channel alignment cause changes in the flow characteristics through, above, and below the new channel. Straightening a

channel does not necessarily eliminate its tendency to meander and an erosion hazard is often developed in, and at both ends of the channel, due to velocity increases, bar formations, and current direction changes.

Alignment

The alignment of the reach should be considered in designing the protective measures.

Straight Alignment

Bank protection for channel sides having straight alignment is usually in the form of a continuous scour-resistant lining or revetment. The lining may be placed on banks which have been sloped sufficiently to be stable under the particular type of lining to be used. For non-rigid types of lining, the slope must be flat enough to prevent downward sliding of the lining material. The principal function of the lining of straight banks is to prevent the normal side scour by straight streamflow which would otherwise cause widening of the channel bottom.

Curved Alignment

In general, more substantial and permanent types of construction should be used on curved sections since revetment failures at these vulnerable points could result in much greater damage than along unobstructed straight reaches of the channel. Curved revetments are subjected to high velocity currents acting against them or continuously flowing adjacent to them.

Undermining of Revetments

Undermining or scouring of the foundation material by high velocity currents has been the original cause of most bank protection failures. In addition to providing protection down to the lowest expected stable grade, additional depth must be provided to reach a footing that cannot be scoured out by temporary high velocity flows or lose its stability through saturation. Regardless of the type of protection installed, deep scour may be expected whenever it is constructed on erodible material and high velocity currents flow adjacent to it.

Methods commonly used to provide protection against undermining are:

1. **Extending the toe trench down to a safe grade and backfilling with heavy rock.**

2. **Anchoring a heavy, flexible mattress to the bottom of the revetment to extend it some distance out into the channel. This mattress will settle progressively as scour takes place and protect the revetment foundation.**

3. **Installing a massive toe of heavy rock where excavation for a deep toe is not practical so that the rock forming the toe will settle in place as scour occurs.**

4. Driving sheet piling to form a continuous protection for the revetment foundation. Such piling should be securely anchored against lateral pressures. Piling should be driven to refusal or well below the expected depth of scour.

5. Installing pervious toe deflector groins to deflect high velocity currents away from the toe of the revetment.

Ends of Revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid outflanking by erosion. Whenever possible or feasible the revetment should be continuous between stable anchorage points, such as bridge abutments or rock outcrops. If this is not practical, the upper and lower ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

Freeboard

Additional freeboard should be provided to prevent overtopping of the revetment at curves and other points where high velocities contact the revetment. Waves are set up by super-critical velocities in these areas and the "climb" on sloping revetments may be appreciable. Since there is no accurate means of determining freeboard requirements for sloping revetments in critical zones, the allowance for freeboard should be based on experience and sound judgment. Under similar conditions the freeboard required for a sloping revetment will always be greater than for a vertical revetment.

Removal of Debris

An essential part of streambank protection is the removal of debris such as stumps, fallen trees, sediment bars, or other obstructions to smooth flow. All revetment designs should be based on the removal of debris being done prior to installing the revetment.

Types of Vegetation

Adapted types of vegetation, properly placed, can provide desirable bank protection in many instances. Perennial grasses should be used rather than annual grasses.

The trees, brush, vines, or grasses selected for use as vegetative protection should not be of an objectionable type. If possible, they should be of some useful variety that will resist erosion, and withstand sedimentation and prolonged inundation.

3. TREATMENT

CHANNEL CLEARING AND SNAGGING

Sediment bars, snags, stumps, debris drifts, trees, brush and objectionable vegetation that disturb the smoothness of flow should be removed from the stream channel. This normally is the first step in streambank protection and, in many cases, may be the only measure needed.

Trees of 4-inch diameter and larger on the bank which are in danger of undercutting and falling into the channel should be cut off and removed. The same is true for those trees which might collect debris and ice drifts along the channel banks. In some cases of unstable soils the weight of growing trees near the channel causes the sloughing of large sections of streambank. These also should be removed. The cleared trees may be used to construct a tree revetment at the site or an adjacent site.

Vegetative growth on the banks, such as brush and grasses, may be trimmed if necessary but generally is left for bank protection.

VEGETATION

Vegetation plays an important part in the control of bank erosion. It may be used alone on small streams, or it may be used along with mechanical measures. There are two problems in using vegetation alone for protection.

1. Establishing the stand.
2. Stabilizing that section of the bank below normal water surface so that vegetation will not be undercut and the bank slough into the stream.

Vegetation is used most successfully above the waterline on properly sloped banks and on the flood plain adjacent to the banks to retard velocity. Vegetation always should be used back of revetments and jetties in the area where silt deposition occurs, on the banks above design flows, and on slopes protected by brush mats.

Many species of plants, shrubs, or trees are suitable for streambank protection planting. The locally available erosion-resistant species best adapted to the soil, moisture, and climatic conditions of a particular site should be used.

In many instances streambank erosion is promoted by overgrazing of the natural vegetation on and adjacent to the banks, or by cultivating too close to the banks. In either event it is desirable to protect the treated area by fencing. If the stream is the source of livestock water, drinking places can be provided by fencing a lane about 50 feet wide down to the water. Such lanes should be installed where the bank is not steep and preferably at the inside of curves in the channel where velocities are low.

JETTED WILLOW POLES FOR BANK PROTECTION

Drive or jet in willow poles on the eroding bank, at or just above the normal waterline. Place two or more rows with the poles 2 to 4 feet apart and staggered between rows (Figure 16-1). The poles should be 6 to 9 feet long and 3 to 5 inches in diameter. About two-thirds of the pole length should be inserted below the ground line. Supplement with plantings of willow cuttings or erosion resistant plants. This type of protection is adapted to the smaller streams where ice damage will not be a problem.

TREE REVETMENT

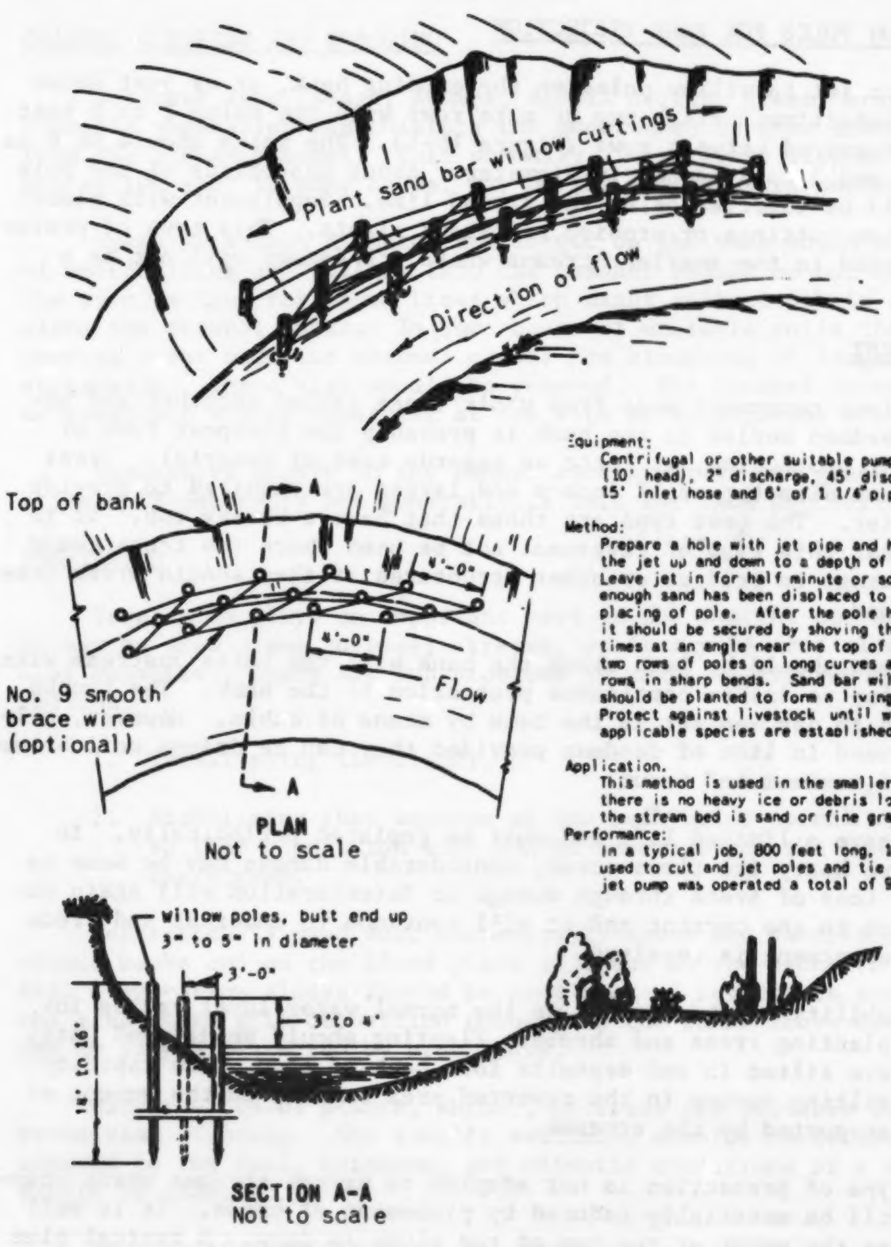
A pervious revetment made from whole trees cabled together and anchored by deadmen buried in the bank is probably the cheapest form of semipermanent protection, at least as regards cost of material. Trees having a trunk diameter of 12 inches and larger are required to provide a good barrier. The best type are those that have a brushy top. It is important that this type of revetment not be used where the trees could do severe damage to bridges or other structures if they should break free during a flood.

The trees should be laid along the bank with the butts upstream with enough overlap to insure continuous protection to the bank. The trunks are anchored to deadmen set in the bank by means of cable. However, piling can be used in lieu of deadmen provided they can be driven well below the point of maximum bed scour.

Trees have a limited life and must be replaced periodically. In streams where heavy ice flows occur, considerable damage may be done to the trees. Loss of trees through damage or deterioration will again expose the bank to the current and it will continue to undercut and erode unless the revetment is repaired.

The stability of the bank above the normal water level can be increased by planting trees and shrubs. Planting should be delayed until the trees have silted in and deposits form back of them. The rapidity with which silting occurs in the revetted area depends on the amount of sediment transported by the streams.

This type of protection is not adapted to narrow streams where channel width will be materially reduced by placement of trees. It is well adapted where the water at the toe of the slope is deep. A typical plan of a tree revetment is shown in Figure 16-2.


Plant sand bar willow cuttings
Direction of flow
Top of bank
A
4'-0"
4'-0"
Flow
No. 9 smooth brace wire (optional)
A
PLAN
Not to scale
Willow poles, butt end up
3" to 5" in diameter
3'-0"
3' to 4'
14' to 16'
SECTION A-A
Not to scale

Equipment:
Centrifugal or other suitable pump, 150 G.P.M., (10' head), 2" discharge, 45' discharge hose, 15' inlet hose and 6' of 1 1/4" pipe for a jet.

Method:
Prepare a hole with jet pipe and hose by working the jet up and down to a depth of 10' to 12'. Leave jet in for half minute or so to be sure enough sand has been displaced to allow easy placing of pole. After the pole has been placed it should be secured by shoving the jet in a few times at an angle near the top of the hole. Use two rows of poles on long curves and four or five rows in sharp bends. Sand bar willow cuttings should be planted to form a living revetment. Protect against livestock until willows or other applicable species are established.

Application.
This method is used in the smaller streams where there is no heavy ice or debris load and where the stream bed is sand or fine gravel.

Performance:
In a typical job, 800 feet long, 15 man days were used to cut and jet poles and tie the brace wires; jet pump was operated a total of 9 hours.

Figure 16-1 Jetted willow poles

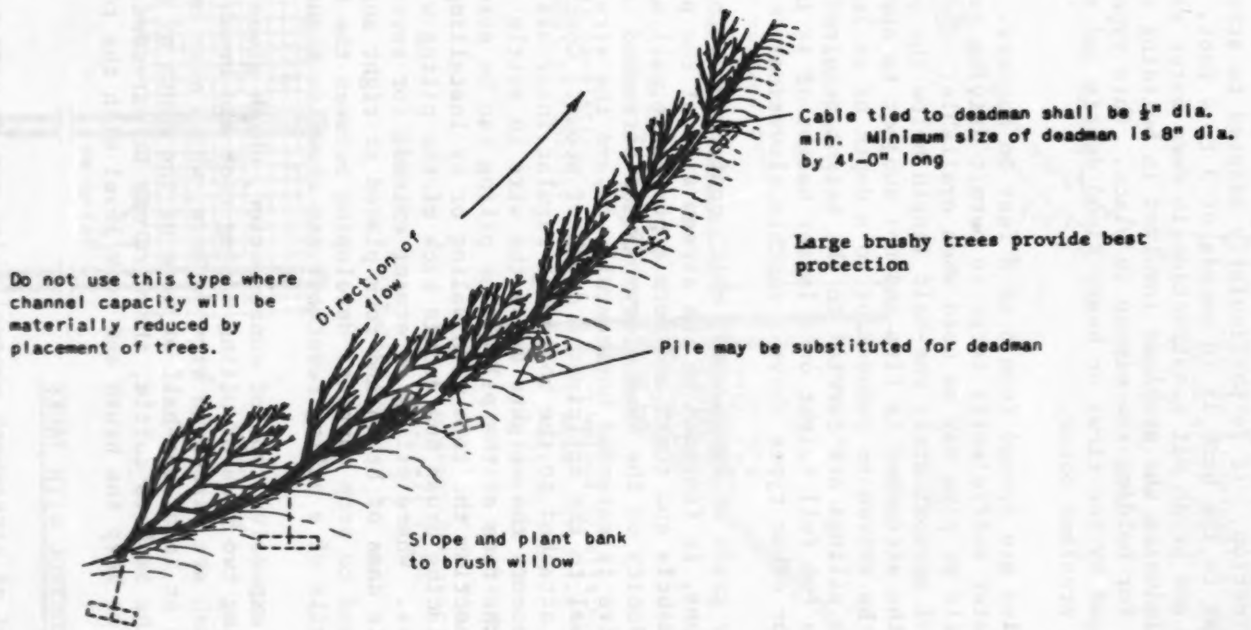

Cable tied to deadman shall be ½" dia. min. Minimum size of deadman is 8" dia. by 4'-0" long
Large brushy trees provide best protection
Pile may be substituted for deadman
Do not use this type where channel capacity will be materially reduced by placement of trees.
Direction of flow
Slope and plant bank to brush willow

Figure 16-2 Tree revetment

PILING REVETMENT WITH WIRE FACING

Continuous piling revetment with a facing of woven wire is a common type of protection. It is particularly adapted to streams where the depth of water next to the bank is in excess of 3 to 4 feet. It has an advantage over riprap and brush mat construction in deep water as it is more economical and eliminates the problems involved in building a stable foundation under water for holding the riprap in place. This type of protection is easily damaged by ice flows or heavy flood debris and should not be used where these problems occur.

The piles are spaced from 6 to 8 feet on centers. Timber piles should have a diameter sufficiently large to permit driving to the required depth. Railroad rails or pipe may be used when available. The pilings are driven to a depth of approximately one-half length below the point of maximum scour. If the streambed is firm and not subject to appreciable scour, the pile should be driven to refusal or to a depth of at least one-half the length. The pilings are carried to the height required to protect the bank, which may be the full height or a lesser height if it is practical to use vegetation or other types above a certain elevation.

A heavy grade of woven wire, which conforms to State Standards and Specifications, is fastened to the stream side of the pile. Its purpose is to collect debris and trash and form a permeable wall which serves to reduce the velocity on the bank side. If the streambed is subject to scour, the woven wire is extended horizontally toward the streambed for a distance at least equal to the anticipated depth of scour. Concrete blocks or other weights are attached to the bottom at regular intervals. During floods when scour occurs the weights cause the wire to settle in a vertical position along the face of the pile. The piling can be strengthened considerably by connecting the tops with waling or by installing a system of cross bracing. Placing brush and debris back of the piling will increase the effectiveness. Where piling revetment extends for several hundred feet, a few permeable dams of brush and rock placed at right angles to the revetment will tend to stop currents developing between the bank and the piling. Typical details of a piling revetment are shown in Figure 16-3.

A more expensive type of construction, which gives more protection, is built by using two rows of piling having rock and brush in between. The rock and brush are placed in wire baskets, which must be set in a trench excavated to at least one-half or more of the depth of the anticipated scour. If the baskets settle, the wire may be extended by adding baskets of material to keep the brush and rock level with the top of the pile.

STREAMBANK CONTROL WITH JACKS

A method of streambank control which can be used rather easily by farmers or ranchers consists of placing one or more rows of "jacks" along the streambank. These jacks are constructed by cutting three poles 10 to 16 feet in length, depending on the depth of the stream which is to be controlled. (Multiply depth of stream by 1.4 to determine length of poles required.) These poles are crossed and wired together at the midpoints. The ends are then tied together with No. 9 wire, as shown in Figure 16-4.

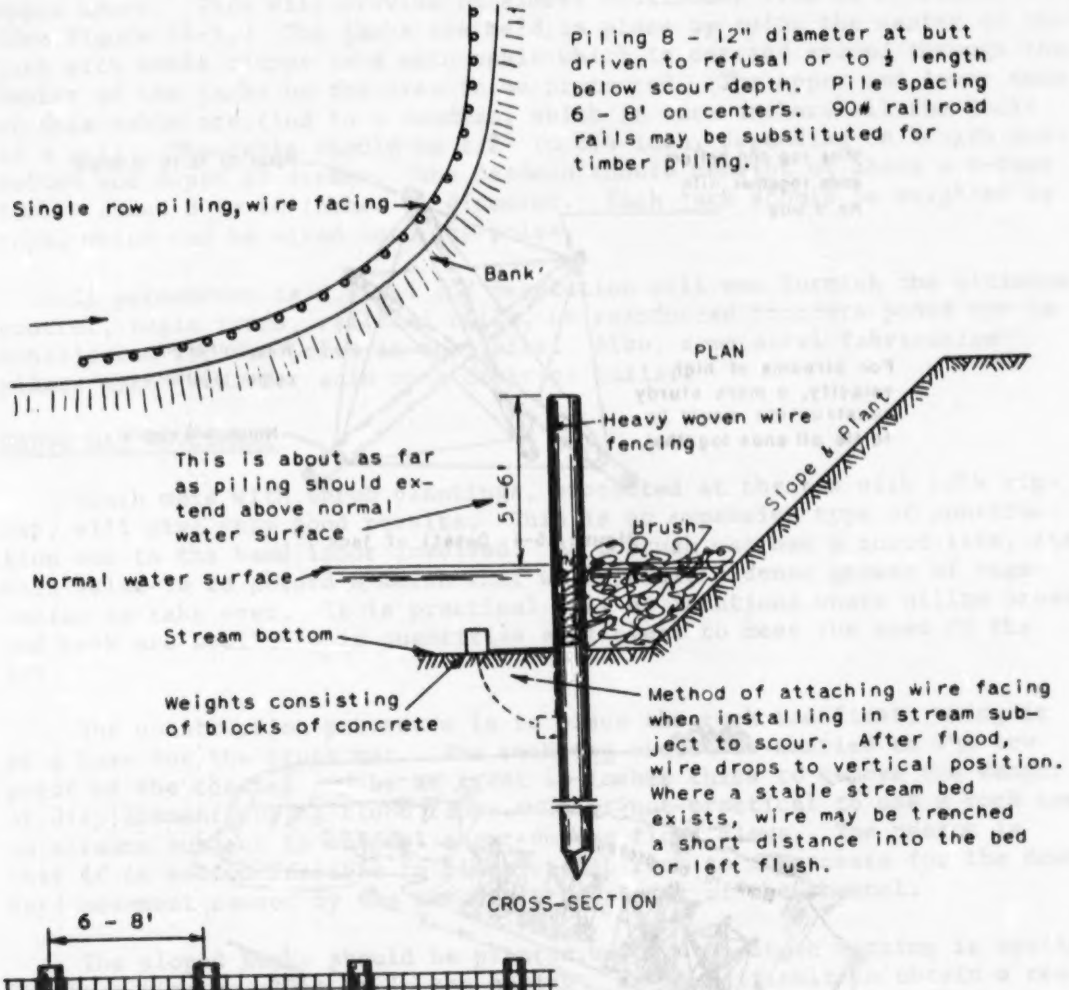

Piling 8 - 12" diameter at butt driven to refusal or to ½ length below scour depth. Pile spacing 6 - 8' on centers. 90# railroad rails may be substituted for timber piling.
Single row piling, wire facing
Bank
PLAN
Heavy woven wire fencing
Slope & Plant
This is about as far as piling should extend above normal water surface
5'-6'
Brush
Normal water surface
Stream bottom
Weights consisting of blocks of concrete
Method of attaching wire facing when installing in stream subject to scour. After flood, wire drops to vertical position. Where a stable stream bed exists, wire may be trenched a short distance into the bed or left flush.
CROSS-SECTION
6 - 8'
Stream bed
Weights
FRONT ELEVATION

Figure 16-3 Piling revetment with wire facing

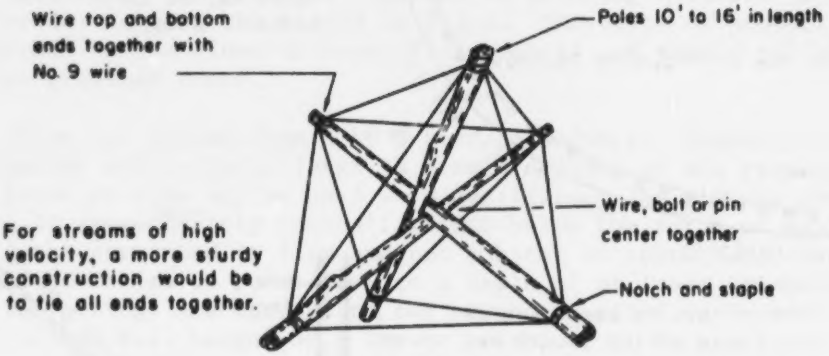

Wire top and bottom ends together with No. 9 wire
Poles 10' to 16' in length
Wire, bolt or pin center together
For streams of high velocity, a more sturdy construction would be to tie all ends together.
Notch and staple

Figure 16-4 Detail of jack

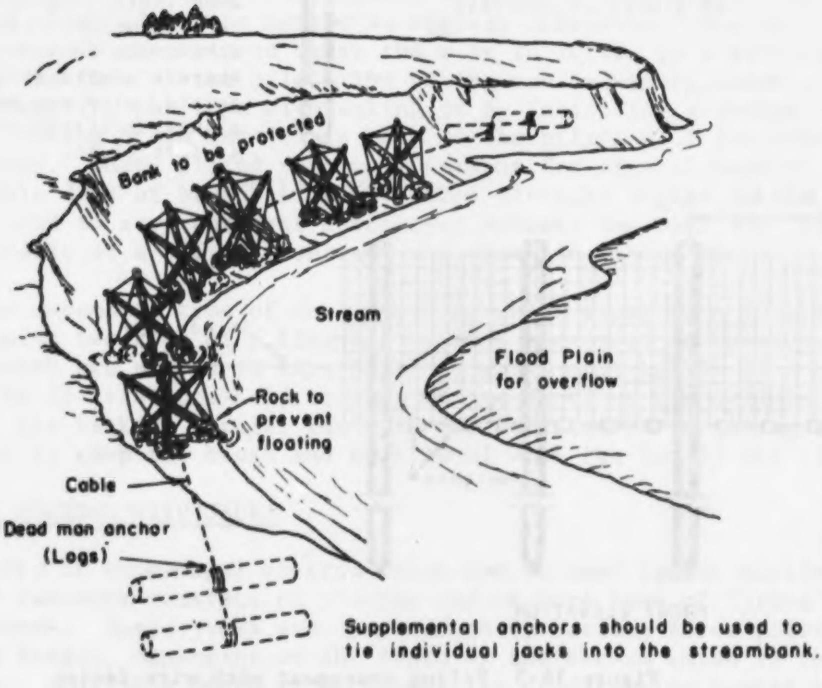

Bank to be protected
Stream
Flood Plain for overflow
Rock to prevent floating
Cable
Dead man anchor (Logs)
Supplemental anchors should be used to tie individual jacks into the streambank.

Figure 16-5 Streambank control with jacks

The jacks should be spaced closely together, with not over one jack space apart. This will provide an almost continuous line of revetment. (See Figure 16-5.) The jacks are held in place by tying the center of the jack with cable clamps to a main cable which is carried around through the center of the jacks on the area to be protected. The upper and lower ends of this cable are tied to a deadman, which in turn anchors all the jacks as a unit. The cable should be 1/2- to 3/4-inch, depending on length protected and depth of stream. The deadman should consist of about a 6-foot timber about 8 to 10 inches in diameter. Each jack should be weighted by rock, which can be wired onto the poles.

If permanence is desired and vegetation will not furnish the ultimate control, angle irons, railroad rails, or reinforced concrete posts can be substituted for the poles in the jacks. Also, some steel fabrication plants make jacks for sale on a contract basis.

BRUSH MAT REVETMENT

Brush mats with shrub plantings, protected at the toe with rock riprap, will give very good results. This is an expensive type of construction due to the hand labor involved. As a brush mat has a short life, its main value is to afford a mulch that will permit a dense growth of vegetation to take over. It is practical only at locations where willow brush and rock are available in quantities sufficient to meet the need of the job.

The construction procedure is to place the rock toe first, using it as a base for the brush mat. The rock toe should be carried to the low point of the channel and be at least 18 inches thick to remove the danger of displacement during flood flows. It is not practical to use a rock toe in streams subject to channel scour during flood flows. The reason is that it is seldom feasible to place enough rock to compensate for the downward movement caused by the temporary deepening of the channel.

The sloped banks should be planted before the brush matting is applied. The best time to plant is in the spring. It is difficult to obtain a reasonable stand when planting new cuttings through a mat.

The brush should be placed over the exposed soil as soon as possible after the bank is planted. Bush willow affords the best material. The brush is laid shingle fashion with the butts pointing up the bank. The brush should be straight enough to lie flat on the bank. The mat should be 6 to 18 inches thick, depending on the size of the stream and the ice hazard. The mat is held in place by driving stakes at an angle crossing each other in pairs or by stakes driven straight into the ground about 2 feet-6 inches on centers and interlacing with No. 9 galvanized wire. After the wire is attached the stakes are driven deeper, which tightens the wire and binds the mat firmly. Stakes driven at an angle and crossed in pairs are only adaptable to small streams. The details of a brush mat riprap are shown in Figure 16-6.

ROCK RIPRAP

Rock riprap, properly placed, is one of the most effective methods of streambank protection. It is costly because of the difficulty of quarrying, transporting and placing the stone and the large quantity of stone that may be needed. However, where stone of a suitable quality and gradation is available within 15 miles of the job, this method of protection should be given consideration. (See Figure 16-7.)

Toe Protection

For successful riprapping, the toe of the revetment must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows. Several methods of toe protection have been discussed previously under the heading, Undermining of Revetments, page 16-6.

Bank Sloping

Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than 1½:1.

Filter Layer

A filter blanket must be placed between the riprap and the bank, except in those cases where the material in the bank to be protected is so graded as to constitute suitable filter material. The filter blanket should be at least 6 inches thick.

Streambed material frequently can be used where it is composed of relatively clean sand and gravel. This provides a good use for sand and gravel bars to be removed. Where natural materials are not available, it will be necessary to specify a manufactured filter which will prevent the removal of fines from the bank material by current and wave action and sloughing of the bank due to sudden dropping of the water level in the stream.

Placing of Stone

It should seldom, if ever, be necessary to hand place the stones in a revetment. While the revetment may have a somewhat less "finished" look, it is adequate to dump the stones and rearrange them with only a minimum of hand labor. However, dumping on a slope must be done in a manner that will not cause separation of the small and large stones. The finished surface should not have pockets of finer materials which would flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a good keyed surface.

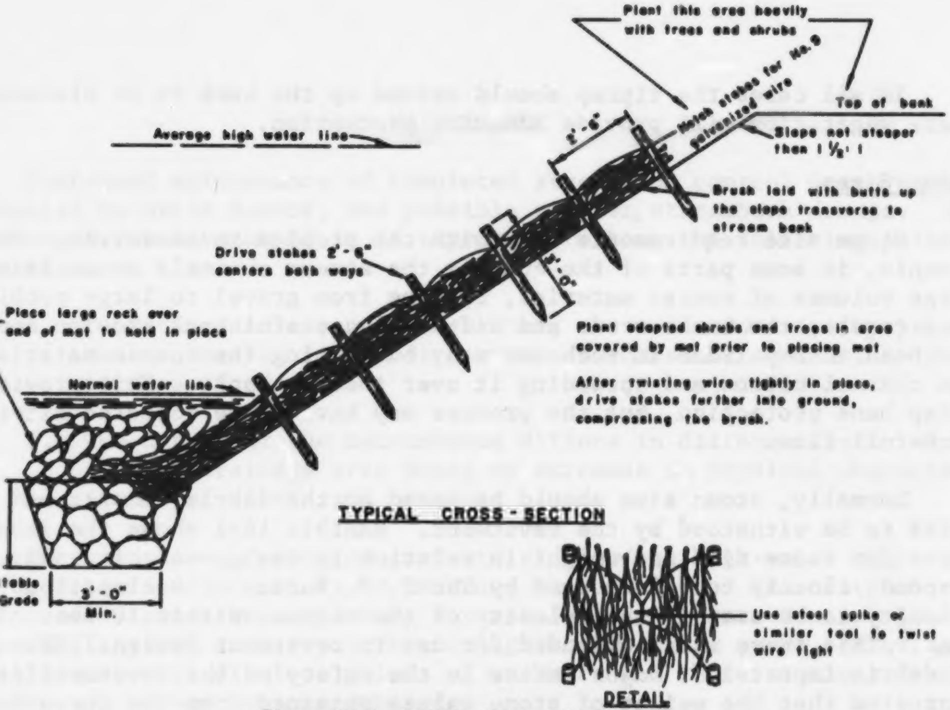

Plant this area heavily with trees and shrubs
Notch stakes for No. 9 galvanized wire
Top of bank
Slope not steeper than 1½ : 1
Average high water line
2'-6"
Brush laid with butts up the slope transverse to stream bank
Drive stakes 2'-6" centers both ways
3'-0"
Place large rock over end of mat to hold in place
Plant adapted shrubs and trees in area covered by mat prior to placing mat
Normal water line
After twisting wire tightly in place, drive stakes further into ground, compressing the brush.
TYPICAL CROSS-SECTION
Stable Grade
3'-0" Min.
Use steel spike or similar tool to twist wire tight
DETAIL

Figure 16-6 BRUSH MAT REVETMENT
Adapted to small streams having a firm stream bed

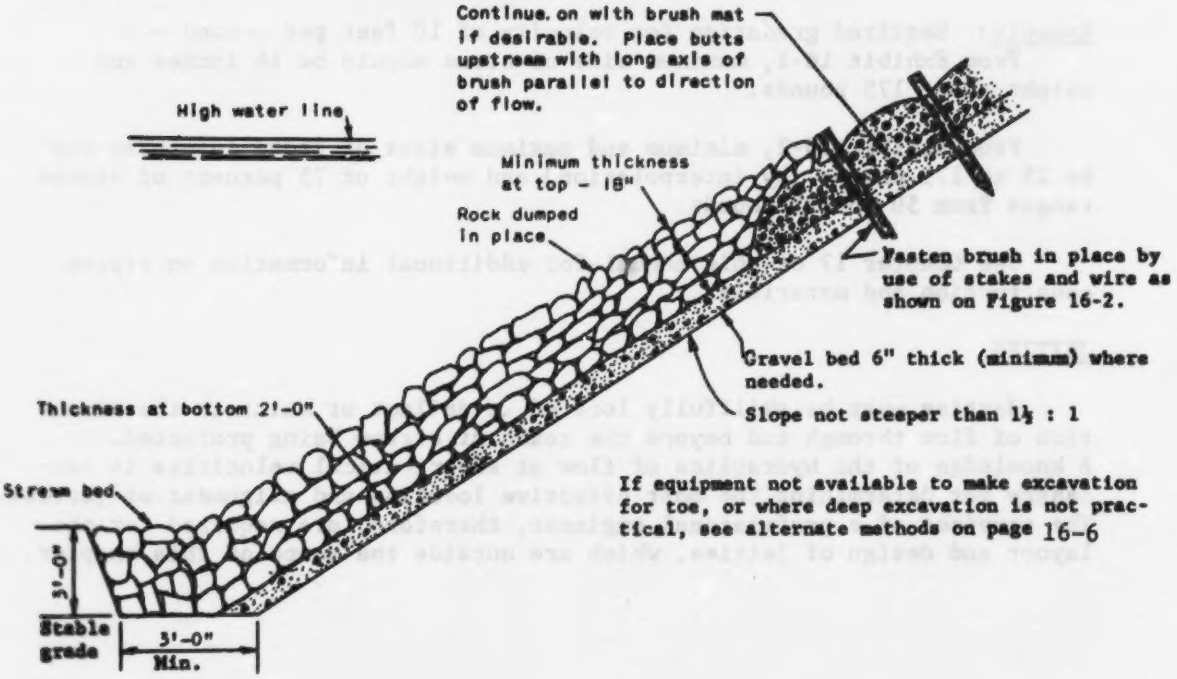

Continue on with brush mat if desirable. Place butts upstream with long axis of brush parallel to direction of flow.
High water line
Minimum thickness at top - 18"
Rock dumped in place
Fasten brush in place by use of stakes and wire as shown on Figure 16-2.
Gravel bed 6" thick (minimum) where needed.
Slope not steeper than 1½ : 1
Thickness at bottom 2'-0"
Stream bed
If equipment not available to make excavation for toe, or where deep excavation is not practical, see alternate methods on page 16-6
3'-0"
Stable grade
3'-0" Min.

Figure 16-7 Dumped rock riprap

In all cases the riprap should extend up the bank to an elevation where vegetation will provide adequate protection.

Stone Sizes

Stone size requirements vary with the problem to be solved. For example, in some parts of the country the stream channels accumulate large volumes of coarse material, ranging from gravel to large cobbles. As a result, the banks erode and widen. Successful bank erosion control has been accomplished in such cases by bulldozing the coarse material from the channel bottom and spreading it over the raw banks. This provides cheap bank protection, but the process may have to be repeated after each bank-full flow.

Normally, stone size should be based on the debris, impact and velocities to be withstood by the revetment. Exhibit 16-1 shows the Isbash curve for stone size and weight in relation to design velocity, which corresponds closely to values used by The U. S. Bureau of Reclamation. The velocity to be used is the velocity of the current within 10 feet of the bank. This curve is recommended for use in revetment design. However, if debris impact is a major factor in the safety of the revetment it is suggested that the weight of stone values obtained from the curve be doubled. Exhibit 16-2 gives the recommended riprap gradation for weight of stone used.

Example: Required gradation for velocity of 10 feet per second:-
From Exhibit 16-1, maximum size of stone should be 14 inches and weight about 175 pounds.

From Exhibit 16-2, minimum and maximum sizes of stone in riprap may be 25 to 175 pounds (by interpolation) and weight of 75 percent of stones ranges from 50 to 175 pounds.

See Chapter 17 of this manual for additional information on riprap construction and materials.

JETTIES

Jetties must be skillfully located to deflect or maintain the direction of flow through and beyond the reach of stream being protected. A knowledge of the hydraulics of flow at supercritical velocities is necessary for determining the most effective location and alignment of jetties. The services of a professional engineer, therefore, are required for the layout and design of jetties, which are outside the scope of this chapter.

4. MAINTENANCE

Continued maintenance of completed streambank control measures is essential to avoid future, and possible greater, streambank damage. In planning for maintenance, it is important to keep the following points in mind:

1. Control measures, once installed, are not automatically permanent. Usually it is not economical to establish absolutely permanent controls.

2. The nature of the maintenance differs in different parts of the general drainage area owing to extremes in physical characteristics of rivers and creeks.

Because the wandering of currents at flood or high-water stages cannot be determined precisely in advance, the amount and intensity of treatment needed cannot be completely foreseen at the start. Careful examination of plantings and structures during the first few years following installation will disclose points of weakness and where sections likely to give way should be strengthened.

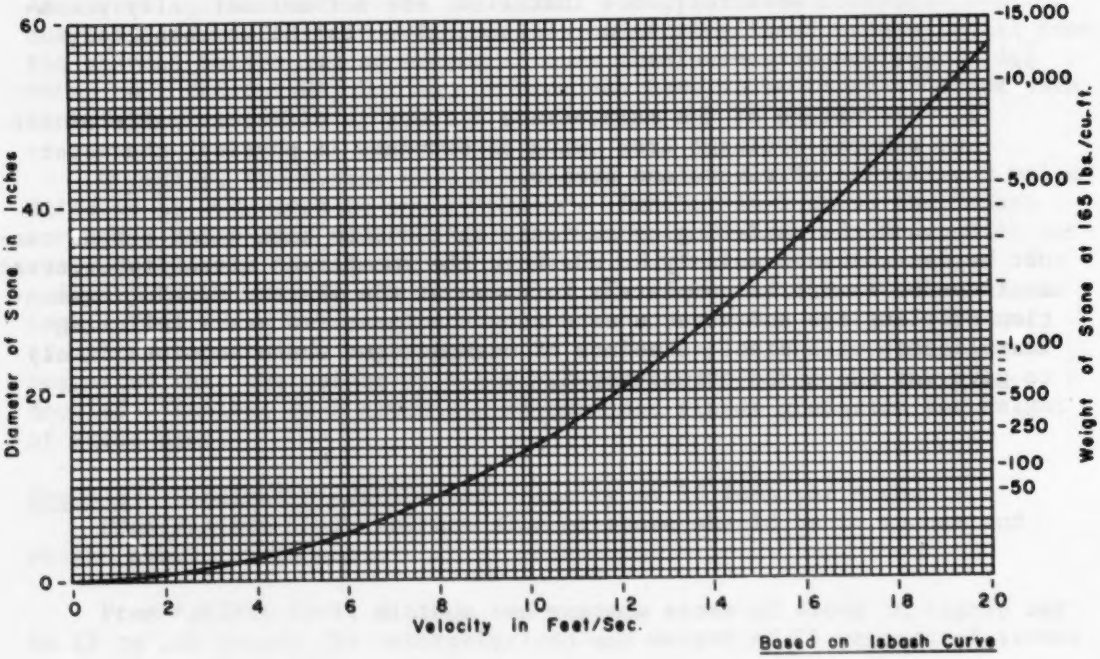


Exhibit 16-1 **Maximum** stone size for riprap

Maximum weight of stone required	Minimum and maximum range in weight of stones	Weight range of 75 percent of stones
(lbs.)	(lbs.)	(lbs.)
150	25 - 150	50 - 150
200	25 - 200	50 - 200
250	25 - 250	50 - 250
400	25 - 400	100 - 400
600	25 - 600	150 - 600
800	25 - 800	200 - 800
1000	50 -1000	250 -1000
1300	50 -1300	325 -1300
1600	50 -1600	400 -1600
2000	75 -2000	600 -2000
2700	100 -2700	800 -2700

Exhibit 16-2. Gradation of riprap

ENGINEERING FIELD MANUAL

CHAPTER 17. CONSTRUCTION AND CONSTRUCTION MATERIALS

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ENGINEERING FIELD MANUAL

CHAPTER 17. CONSTRUCTION AND CONSTRUCTION MATERIALS

1. GENERAL

DEFINITION

Construction is the act of putting together the various parts of, and installing, structures or measures according to approved plans and specifications.

INTRODUCTION

Each employee at the work unit level who has responsibility for practice layout and inspection should know:

1. **The basic principles required for acceptable structure installation.**
2. **The types and quality of materials commonly used in the construction of conservation practices.**
3. **Methods and procedures for installing earthwork, concrete, reinforcing steel, pipe, watergates, metalwork, woodwork, masonry, and rock riprap.**
4. **State Standards and Specifications and policy requirements.**

2. SURVEYS FOR CONSTRUCTION

DETAIL AND ACCURACY

Even the simplest installation requires layout and stakes to control the work. The amount of staking required is related to the kind and complexity of the work, and the facilities and experience of the builder.

The actual location of the stakes should be determined by:

1. **The ease of access and use by the builder in installing the work.**
2. **The availability for use in checking during construction.**
3. **Permanence during the period of installation.**

The importance of accuracy in taking off dimensions, elevations, or other layout data from the drawings, and the actual field layout cannot be overstressed. Errors in construction layout may result in extra cost to the owner and embarrassment to the technician.

The technician making the layout should always check the drawings; check the field layout, including markings on the stakes; and recheck all field note computations.

Do not take shortcuts to save time.

METHODS AND DOCUMENTATION

Detailed survey procedures for structure layouts and the format for documenting the field notes for the many kinds of installations that are common to farm conservation practices is beyond the scope of this chapter.

Surveying equipment, kinds of surveys, and documentation of field notes are outlined in Chapter 1 of this manual.

Procedures for individual practice layout and field note documentation are also set forth in various chapters of this manual. Follow standard Service policy for recording engineering survey notes.

Suggested procedures for construction layout and documentation of field notes for the more complex construction projects can also be found in the SCS National Engineering Handbook, Section 19, Chapter 2 (1).

Technicians responsible for layout and inspection should become familiar with the requirements and suggested procedures given in the above reference. Standardization of the construction layout is important to accuracy, understanding, and saving of time.

CONSULTATION WITH THE CONTRACTOR AND THE OWNER

Construction stakes are set for the use of the party doing the construction. Prior to making the construction layout, an effort should be made to consult with the contractor and get his suggestions as to what stakes he would prefer and how they should be marked.

After the work is staked and prior to starting construction, it is good procedure for the technician to familiarize the contractor with the location of all the stakes, how they are marked, datums or structure limits represented, and what stakes are to be protected during the work. At this time any special requirements or critical conditions that pertain to the job can be discussed. It is general policy to allow the contractor latitude in planning and executing the work. However, the technician should know the requirements in the drawings and specifications, and if specified methods or materials are required the contractor should understand these details.

This review also presents a good occasion to discuss the quality of work or finish that will be required. If the contractor is informed of what will be acceptable workmanship, it will help him carry out the work and avoid complications and disagreements.

It is desirable that the owner of the facility or his representative be a party to the preconstruction review of the job. The technician should always keep the owner informed and obtain his approval prior to any action taken with the contractor that might increase the cost or change the scope of the installation.

3. EARTHWORK

EXCAVATION

Foundation Preparation

Clearing and Grubbing

Construction sites often support trees, brush, and other woody growth including large roots that require removal prior to further excavation or placing fill.

The degree of clearing and grubbing required in the initial operation is related to the kind of structure being installed. The drawings for the project should outline the limits, the kind and depth of removal and the method of disposal. The contractor should be shown the limits of the work as staked on the ground, including any trees that are to remain or require special protection.

It should be determined that:

1. The limits for clearing and grubbing are clearly marked.
2. All materials are removed and disposed of as required.
3. The contractor's operations do not damage adjacent property.
4. Adequate care is taken to protect the safety of the public.

Stripping

Stripping excavation consists of removal of materials that are unsuitable for structure foundations. This is a common requirement for the construction of dams, dikes, and similar water-impounding embankments. These excavations consist of removing surface soils which contain vegetation and root growth. They may also include soils that, due to inherent or wet conditions, will not support the structure. The removal of all unsuitable materials is emphasized to insure the stability and safety of the structure. If the technician is not confident of the quality of the exposed foundation material, he should request engineering assistance from his supervisor.

Some important check items are:

1. Make sure the limits for stripping are staked in the field.
2. Take preconstruction cross sections when required for yardage payments.
3. See that all unsuitable materials are removed and disposed of as required.
4. Determine if provisions for controlling surface water and dewatering the foundation area are necessary.

Scarifying

Scarifying or loosening the foundation surface area for embankments, under certain conditions, improves the bond between the embankment and the foundation materials. The depth of the scarifying should be limited to 6 inches or less to insure satisfactory blending and compaction of the first lift of the embankment and the foundation. This operation is applicable primarily to fine grained soils that present a smooth slick surface after stripping. Scarifying is not applicable when the foundation consists primarily of coarse grained soils or stony material. Rock larger than 6 inches in diameter that is brought to the surface by the scarifier should be removed prior to placing embankment.

Compaction

Compaction of the foundation for embankment is desirable and often required, especially when fine grained soil materials predominate. Compaction should be delayed until the embankment construction is ready to start. The moisture content of the foundation should be similar to the requirements for the embankment. Equipment provided for compaction of the embankment should completely traverse the foundation area a sufficient number of trips to result in acceptable densities.

Uniform densities of foundation material for structures are essential. All soil materials added to replace over-excavation should be moistened, as required, and compacted to provide uniform support.

Preparing Rock Surfaces

It is important to get good bond between the impervious embankment and any extensive rock surface. The field operations should be carefully conducted to fulfill all the requirements of the drawings and specifications. Deep, abrupt irregularities and overhanging surfaces that are difficult to backfill should be removed. Keyways, trenches, and vertical abutments should be sloped and shaped to provide smooth contact for the embankment. Blasting in foundation areas is not recommended except in unusual situations, and then only under careful control of light charges. All loose rock and pervious materials should be removed from the rock surface. Semihard rock, such as shales, that break down when exposed should be left covered or protected from the elements until just before placing the embankment.

Rock foundations for structures, other than embankments, are commonly over-excavated and backfilled to grade. The amount and kind of backfill and the compaction should meet all the requirements for subgrade or bedding material.

Cutoff Trench

Cutoff trench excavation may be considered a continuation of the foundation preparation, and is often specified for earth embankments that impound water. The purpose is to provide a location for placing controlled embankment that will reduce the volume of seepage through the foundation of the embankment. The location of the trench should be as shown on the drawings. The depth should be as specified, or adjusted to the suitability of the exposed material in the excavation. The bottom width of the trench should be adequate for operating a carryall or scraper and compacting equipment. The trench sides should always be sloped 1:1 or flatter.

Channels

Channel construction and rehabilitation have application to various practices; i.e., stream channels, floodwater diversions, irrigation, and drainage. Designs for these practices are based on computed cross sections and grades. The project should be accurately staked in accordance with these designs, and the installation checked to determine that all requirements are met. Special attention should be given to the disposal of the excavated materials. Often provisions are included for the use of these materials in adjacent dikes or other embankments, requiring that specific selection and routing of the materials be followed. When excavated material is placed as waste adjacent to the channel, consideration should be given to the stability of the channel side slope. If during construction possible failure of the bank is indicated, the technician should immediately consult with his supervisor and the owner to determine the corrective action required. This may call for the use of a wider berm, placing the waste material at a shallower depth, or complete removal of the excavated material. All excavated surfaces should be constructed to line and grade with a uniform machine finish and waste material shaped in accordance with State Standards and Specifications.

Trenches

Trench excavation relates primarily to the installation of pipelines, drain tile, and structure drainage systems. These excavations require field layout and inspection at critical points during construction. All trenches should be excavated to the required grade or specified over-excavation. Material removed from the trench should be placed a safe distance from the excavation to prevent excessive loading on the trench walls.

Borrow Areas

Borrow areas usually are necessary to supplement required excavations for the construction of dams and other items of earthwork. All borrow areas shown on the drawings should be staked in the field. The exact location of excavation in the borrow area and the requirements for mixing, routing of equipment or other controls should be as specified or as directed by the technician. He should determine that the materials excavated are similar in quality to those considered in the design for the work. Materials that do not conform should not be used unless approved by the designer.

EMBANKMENT AND STRUCTURE BACKFILL

Dams and Dikes

Quality of Materials

The suitability and amount of materials for fill construction should be determined in the design phase with sufficient exploration and testing to insure that good materials are available at or near the site.

The technician should have knowledge of the Unified Soil Classification System, be able to identify soil groups in the field, and know which soils are suitable for constructing earth embankments. A discussion of procedures for field identification and adaptability of soils is presented in Chapter 4 of this manual. Additional information on testing and adaptability of soils may be found in references (1), (2), and (3).

It is important that the technician verify the quality of the materials as they are being placed during construction. If a questionable change in soil classification occurs, he should consult with his supervisor to determine the suitability of the new material.

Control of Moisture

Water is added to dry soils to improve the lubrication and the workability of the individual particles to form a dense mass when compacted. The maximum dry density (weight in pounds per cubic foot) of the embankment is related to the moisture content and the compactive effort. The technician should be familiar with the moisture density relationship as it applies to moisture control and the compaction of soils. Detailed discussion on this relationship and the methods for making field tests for moisture and density may be found in the National Engineering Handbook, Section 19, Chapters 3 and 4, (1) and in the "Earth Manual," Department of the Interior, Bureau of Reclamation (2).

Fill materials used to construct embankments to meet specified densities should contain uniform moisture in the proper amount. When the fill material is deficient in moisture, better moisture distribution can be obtained by prewetting the borrow area. Adding water to the borrow material after placing on the fill requires careful mixing to distribute the moisture. The use of blades, disks, plows, or other equipment is required for this purpose. Failure to perform the mixing operation carefully results in dry layers and nonuniform densities.

All fill material used to construct embankments that control or store water, whether tested or not, should contain sufficient moisture to permit satisfactory compaction.

Soils that are too wet when excavated from the borrow should be dried to the required moisture content or wasted. Moisture control is a difficult but important phase of embankment construction.

Loading and Placing

Earth embankments usually are constructed from the most suitable materials available at the site; therefore, it is important to select sites where good construction materials are present. Small embankments are often designed as homogeneous fills. Large structures or sites that have limited quantities of impermeable soils may be designed as zoned fills, with the more impermeable material placed as a cutoff and the permeable material placed at less strategic points such as the downstream section of the embankment. The technician in such cases needs to be familiar with the quantity and quality of the borrow materials in order to select and place them in the embankment to produce the zones or transitions specified in the design.

It is common for borrow areas to contain layers or lenses of materials that vary in texture. Often it is possible to use the poor material. The contractor, by selecting the materials at the time of loading and by proper routing and control of the haul equipment, can place the materials in embankment zones where they are suitable for use.

Fill material should not be placed until the foundation preparation has been approved. All water should be removed from the foundation prior to placing the embankment. All embankment material should be placed in uniform horizontal layers not to exceed the specified thickness. For zoned fills, care is required to prevent intermixing of the materials. Fill material should not contain frozen materials or be placed on frozen surfaces.

Compaction

The requirements for compaction and the amount of control depend on the purpose, size, and hazard conditions of the structure involved. The drawings and specifications for the work will state the degree of compaction or the equipment methods required. To accomplish acceptable compaction, the fill material should contain moisture within the specified range, and be spread in uniform loose layers. Each layer is compacted before another layer is added. When the fill is to be compacted to a specified density, the contractor is to select the compacting equipment, and the sequence of operations necessary to obtain the required density.

Tamping rollers (sheepsfoot type) have proven to be very satisfactory for compacting fine-grained plastic soils. Zones containing a large percentage of sand, gravel, or large rock may be consolidated with vibratory smooth drum, pneumatic or grid-type rollers. Portions of the embankment that are not accessible to heavy rollers need to be hand tamped or compacted with small manually directed tampers to the same density as other similar zones of the embankment. For smaller embankments, compaction may be obtained by routing of the construction equipment.

Density

Embankments placed at a specified density require that actual in-place tests be made of the embankment to be sure that the dry density of the embankment meets the requirements. For certain soil or structural conditions it may also be required that the moisture content of the fill material be maintained within specified limits of optimum. For these conditions, detailed inspection is required. The technician should have knowledge of the test equipment and procedures that are applicable to the work. Testing procedures, equipment and test report forms are discussed or referenced in National Engineering Handbook, Section 19, Chapter 4 under "Soils." The sand cone calibrated cylinder or rubber balloon methods for determining volumes are commonly used for fine grained soils. A compaction curve (moisture density) representative of the borrow being placed should be available for comparison with results determined for the embankment. A new curve may be required if the gradation of the borrow changes. Individual tests should be made when it is questionable whether fill densities are meeting requirements. Location of each test made on the fill and complete test data should be recorded on referenced standard forms.

Embankments which, based on experience, do not require density tests and are compacted by specified equipment procedures, may be accepted as meeting the density requirements. The specifications for equipment, the number of passes, and the coverage of each layer of the embankment by the compaction equipment should be checked as the work progresses.

Structure Backfill

The importance of the quality of the materials and the proper placing of structure backfill is often overlooked. Failure of the backfill can endanger the structure. Backfill placed to prevent movement of water should be carefully selected and compacted. The backfill should be fine grained, reasonably plastic, and free from rock over 2 inches in size. The moisture content should be maintained in a range similar to embankment fill. The backfill should be placed in layers less than 4 inches in thickness and distributed uniformly around the structure. Each layer requires compaction by hand tampers or small power equipment. Where a fill is to be placed against walls, they should be checked as compaction progresses to make sure that overstressing and damage to the structures do not occur.

Finish and Cleanup

A little extra effort in smoothing earthwork, finishing exposed surfaces of concrete, and cleanup of the job site creates pride in the completed structure by all parties concerned. A job may be constructed according to the requirements but if the finish and final cleanup of the structure and worksite is not completed in a workmanlike manner, it reflects on the adequacy of the entire job.

4. CONCRETE

CHARACTERISTICS AND PERFORMANCE

Structures made of good quality concrete have the properties of strength, rigidity and watertightness, and resistance to wear, weather and other destructive agents.

Concrete is high in compressive strength, or its ability to resist crushing. It is relatively weak in tensile strength, or its ability to resist bending. Tensile stresses in concrete structures are caused by earth or water pressures, structure dead loads, and expansion and contraction due to temperature changes.

In properly made concrete each particle of the fine and coarse aggregate is completely surrounded, and all spaces between aggregate particles are completely filled by the water-cement paste. This paste is the cementing medium which binds the aggregates into a solid mass. The cementing action is due to chemical reactions between the cement and water. The setting or hardening action is quite rapid for the first two weeks under favorable temperature and moisture conditions. Additional strength is attained at a decreasing rate for a period of months.

Fine and coarse aggregates make up 65 to 75 percent of the volume of the concrete mix; therefore, care in their selection is important. They should be graded to obtain the best economy from the paste, and consist of particles having ample strength and resistance to exposure conditions.

The detail and thoroughness exerted in the design and testing of the mix should be in line with the size and requirements of the structure.

MATERIALS

Cement

Portland cement for small jobs usually is delivered in paper sacks containing 94 pounds which is equal to 1 cubic foot in volume. All cement at the time of use should be free from lumps that cannot be pulverized between the thumb and fingers. Portland cement should be stored in a dry place.

Portland cement is manufactured in 5 types to meet construction requirements, as follows:

Type I - Normal Portland Cement - Suitable for all uses when the special properties of the other types are not required.

Type II - Modified Portland Cement - Has improved resistance to sulphate attack, and should be used where sulphate concentrations are higher than normal but are not unusually severe.

Type III - High Early Strength Portland Cement - For use where high strengths are required at an early date, or in cold weather to reduce heating period.

Type IV - Low Heat Portland Cement - For use where amount and rate of heat generation must be kept to a minimum such as massive concrete structures. Not generally suited to Service concrete construction.

Type V - High Sulphate-Resistant Portland Cement - Used in concrete exposed to severe sulphate action.

The suffix "A" when added to Types I, II and III designates that an air entraining agent has been added to the portland cement.

Water

Mixing water should be clean and free from oil, alkali or acid. In general, water that is fit to drink is suitable for use; however, water that contains excessive quantities of sulphates should be avoided, even though it may be fit to drink.

Aggregates

Fine and coarse aggregates should be hard, free from dirt, and organic materials. Aggregates containing silt and clay particles in excess of 2 percent by weight should not be used.

Fine aggregates consist of natural or manufactured sand. Concrete sand should contain particles ranging in size from 1/4 inch to material retained on a 200-mesh screen. Good gradation from coarse to fine is important for quality and workability of the concrete.

Coarse aggregate may consist of gravel, crushed stone, or other suitable materials larger than 1/4 inch. Aggregates that are sound, hard, and durable are best suited for making concrete. Materials that are chemically reactive, soft or flaky, or wear rapidly are unsatisfactory. The material should be well graded from maximum nominal size to 1/4 inch.

The maximum size of coarse aggregate depends on the thickness of wall or slab, and the amount of steel reinforcement. In general, for walls or slabs over 6 inches thick containing a single row of steel, aggregate graded up to 1-1/2 inches may be used. For a wall thickness of less than 6 inches, aggregate graded up to 1 inch is recommended since it is easier to place. These are standard separation sizes and are usually available at commercial aggregate plants.

It is good economy to use washed and screened aggregates that are known to produce good concrete. Bank-run (pit) sand-gravel, even though hard and of acceptable gradation, may not be suitable. Pit aggregates often contain excessive amounts of soil and organic material. Prior to the use of these materials a quick silt test should be made. Proceed as follows:

1. Fill a fruit jar to a depth of 2 inches with a representative sample of the aggregate.

2. Add water until jar is about 3/4 full.

3. Shake vigorously for 2 minutes; complete by agitating to level the material.

4. Let the mixture stand for 1 hour, then measure depth of silt layer on top of sand.

If the layer is more than 1/8 inch in thickness, the aggregate is unsuitable for making concrete.

Air Entrainment

Air entraining admixtures may be contained in the cement (designated by suffix "A") or they may be added to the batch at the time of mixing. These materials, which include various compounds such as natural wood resins, fats, sulfonated compounds and oils, create a vast number of minute air bubbles in the concrete. Adding air by this method improves the workability and placing of the concrete, and also increases the resistance to severe frost and chemical action. The air content of the mix should be maintained between 3 and 7 percent. Control of the air content of the mix is more difficult when air-entrained cement is used, due to the fixed amount added to the cement. Control is more satisfactory when the admixture, usually a liquid, is added to the water at the time of mixing. The amount recommended by the manufacturer will usually produce the required air content. Because of its proven service record and improvement in workability, air entrained concrete is recommended for all work.

PROPORTIONING THE MIX

All concrete needs to consist of a workable mix that can be placed and finished in an acceptable manner. Such mixes should contain sufficient cement paste to bind the aggregates together and enough cement and sand to give smooth surfaces free from honeycomb.

For small amounts of concrete the following suggested mix will produce good concrete and is simple to batch on the job: one sack cement (1 cubic foot), 2 cubic feet sand, 3-1/2 cubic feet of gravel or crushed rock and a maximum of 6 gallons of water. The proportions of sand and coarse aggregate may require slight variation if the mix does not meet slump or placing requirements.

For jobs that require large amounts of concrete, a more refined mix can be justified. Service engineers should work with the work unit staff and the concrete supplier and select a mix that is economical and satisfies the job requirements.

The Portland Cement Association publication, Design and Control of Concrete Mixtures (4), presents excellent coverage on the details of design, placing and finishing of concrete. The publication is recommended for study by field technicians.

Water-Cement Ratio

The principal requirements for concrete are strength, durability, workability and economy. A well-proportioned mix should result in good balance among these four essentials. The first step in designing the mix is to select the water-cement ratio (gallons-per-bag cement) which will produce concrete of the desired strength and durability. The next step is finding a suitable combination of aggregates which will give good workability when mixed with the selected water-cement content. If the ratio of water to cement is maintained constant, the potential compressive strength of the concrete is practically constant, providing the mix is plastic and workable. It is more economical to design the mix to use the maximum amount of coarse aggregate within the limits of acceptable workability.

Allowing for Moisture in the Aggregates

The selection of the water-cement ratio assumes the maximum gross amount of available water. Most aggregates contain some free water that is available in the mix. The amount in the coarse aggregate is generally small and can be disregarded. Sand can contain a surprising amount of water which should be evaluated.

For small jobs a field test may be made by squeezing a sample of the wet sand in the hand.

Dry sand - Air dry is seldom available for use. No correction needed.

Damp sand - Feels slightly damp to the touch but leaves little moisture on the hands, and represents about 1/4 gallon of water per cubic foot or about 2 percent by weight.

Wet sand - Feels wet and leaves a little moisture on the hands after handling. This indicates approximately 1/2 gallon of water per cubic foot or about 4 percent moisture by weight.

Very wet sand - Is dripping wet when delivered to the job and leaves appreciable amounts of water on the hands. Such aggregate carries 3/4 to 1-1/4 gallons of water per cubic foot, or 6 to 9 percent by weight.

It is important to control the amount of mixing water added at the mixer, taking into consideration the amount of moisture in the fine aggregate. The following example represents the corrections required for variations in moisture content:

1 gallon water = 8.33 pounds 1 bag cement = 94 pounds

$$\text{Water-cement ratio} = 6 \text{ gallons per bag cement}$$

$$= \frac{6(8.33)}{94} = \frac{50}{94} = .53$$

1/2 bag batch

Cement per batch (pounds)	Quantity of water to add when sand is: Dry	Damp	Wet	Very Wet
	(gallons)			
47	3	2-1/2	2	1-1/2

Size and Gradation of Aggregates

Sharp, rough or flat and elongated aggregate particles of coarse aggregate, such as crushed rock, require more fine aggregate and cement to produce good workable concrete than natural sands and gravels which usually are made up of rounded particles. The gradation of, or particle-size distribution in, the fine and coarse aggregate is important because of its effect on the workability, porosity, shrinkage and economy of the mix. Very fine sands require extra cement. Coarse sands give a harsh, unworkable mix. The larger the size of the coarse aggregate the less cement and water required for a given quality. Variations in grading of the coarse aggregate should be compensated for by varying the amount of sand. Uniformly graded aggregates are easier to proportion and should be used when available.

Consistency

Consistency is related to the workability of the mix and is measured by the use of the slump cone. The methods for sampling fresh concrete and for making the slump test are outlined in National Engineering Handbook, Section 19, Chapter 4, Tests C-1 and C-2. The consistency is commonly referred to as the slump of the mix.

Concrete having good consistency is smooth and workable and will place and finish with minimum effort. When worked with a trowel it has a sticky feel. The coarse aggregates do not separate when the concrete is placed in the forms, and excessive free water does not appear on the surface after it is consolidated. A slump of 3 to 4 inches, as measured by the slump cone, is satisfactory for most slab and form construction.

CONTROL OF JOB MIX

Small quantities of concrete mixed on the job are often batched by volume. The volume of a container to be used for measurement can be determined by filling the container with water and weighing it. A cubic foot of water weighs 62.4 pounds. The calibrated containers may then be used to measure the required amount of water, cement, and fine and coarse aggregates for batching. If wheelbarrows are used to convey aggregates from the stockpile to the mixer, a mark may be established in the wheelbarrow bed to represent the required measured volume of the aggregates. It is important that the aggregates in the stockpile are uniform in gradation and accurately measured. Small variations in quantities of the ingredients have an appreciable effect on the quality and slump of the concrete.

More refinement and accuracy may be accomplished by batching by weight. This refinement is justified for larger jobs. Commercial transit mix concrete frequently is used for projects requiring 5 cubic yards or more. Such plants batch by weight and will deliver the mix specified for the work. Procedures for determining or checking the batch weights for the mix are outlined in the publication, Design and Control of Concrete Mixtures, Portland Cement Association.

MIXING

Concrete should be mixed until it is uniform in appearance with all ingredients uniformly distributed. Mixers should not be loaded in excess of their rated capacity and should be operated at the speeds for which they were designed. Concrete may be satisfactorily mixed on the job in any type of revolving drum mixer, provided the mixing blades are clean and not badly worn, and the capacity and speed of the drum are properly maintained. The minimum mixing time after all ingredients are in the drum should be 1-1/2 minutes. A longer period may be used if the mix is not uniform at the end of this time. A part of the mixing water should precede the placing of dry materials into the mixer, and more is added during the charging operation. The final amount of the mixing water should then be added after all the other ingredients are in the mixer. No material should be permitted to escape from the drum during the mixing operation.

Concrete delivered in transit mixers should be mixed about 75 revolutions at mixing speed and then maintained at agitation speed until delivered at the job.

PLACING

Before any concrete is placed, the excavations, forms, steel reinforcement, embedded fixtures, and joints should be inspected to determine that their requirements have been met. Earth surfaces should be firm, moist, and free of frost and ice. Rock surfaces should be reasonably smooth, moist, and free of loose material. Form surfaces should be oiled or moistened just prior to placing concrete. All sawdust, scrap lumber and other debris should be removed from the areas to receive concrete.

The concrete should be placed in the forms as soon as possible, normally not longer than 1-1/2 hours after mixing.

Concrete may be transported by many methods, such as wheelbarrows, push buggies, chutes, or crane buckets. For small onsite mixing, the wheelbarrow is a common means of transportation. Often direct delivery can be made from the transit mix trucks to the forms. Whatever method is used, care is required to prevent separation of the coarse and fine particles commonly known as segregation.

To avoid segregation of materials, concrete should not be allowed to drop freely more than 5 feet. Drop chutes made of metal or rubber should be used in wall sections when the free fall exceeds 5 feet. The drop chutes can be made rectangular to fit between the reinforcing steel. The concrete should be placed as nearly as practicable in its final location. Concrete placed in large quantities and allowed to run, or to be moved over a long distance, results in segregation.

Slabs are usually placed to full thickness in one continuous operation. Formed concrete should be placed in layers not to exceed about 18 inches. Special precaution is required to schedule placing successive layers before the concrete has started to set. "Cold" joints are unsightly and may permit leakage and deterioration of the concrete.

Consolidation

The fresh concrete should be consolidated as soon as it is deposited in the work. Internal vibrators and tamping and spading may be used. Vibrators should be inserted vertically and allowed to penetrate into the previously placed plastic layer. The vibrator head should be moved slowly up and down on about an 18-inch spacing. Allowing the vibrator to remain stationary for more than a few seconds may cause the concrete to segregate. Only sufficient vibration is required to consolidate each layer with the previously placed layer and to completely fill the corners and embed the reinforcement and other items. The finish next to the forms may be improved by spading with spudding hoes or wood strips, which tends to release trapped air and force the coarse aggregate away from the form surface.

Construction of Joints

The construction joint is the most common type of joint required in small concrete structures. It is not constructed as a plane of weakness but is a procedure used when the concrete cannot be placed in a single operation. Joints should be made straight and horizontal or vertical. The surface of the joint should be formed with a recess or keyway when so specified on the drawings. Some improvement in the bond may be derived from this type of joint provided it is properly formed and cleaned.

Extra care is needed to insure bonding of the newly placed concrete to that previously placed. The surfaces of existing concrete should be thoroughly cleaned to remove loose surface material and expose solid aggregates. Sandblasting or steel wire brushes are commonly used for this operation. The exposed surfaces should be washed or air blasted to remove all loose material and should be damp at the time fresh concrete is placed.

Contraction and Expansion Joints

All concrete contains water in excess of that required for hydration of the cement. The evaporation of the excess water creates tensile stress in the concrete due to shrinkage. Concrete movement is also caused by changes in temperature. During cold weather the material will contract or shrink. If these stresses are not relieved by providing contraction joints, unsightly random cracks are likely to develop.

Contraction joints should be located as shown on the drawings. The spacing, normally set by a professional engineer, may vary from 10 to 25 feet depending on the kind of structure and the exposure conditions. The joints are installed by cutting with a special saw or by forming grooves that extend about 1/4 to 1/5 of total thickness into the slab or wall. The joints often referred to as "dummy joints," should be uniform in depth and alignment. Cracks as they occur are expected to form naturally at the weakened section.

Expansion joints are installed to relieve severe thrust which is often caused by high temperature. Premolded bituminous strip materials or compositions of cork or rubber having a width equal to the slab or wall thickness, and varying from 1/4- to 1/2-inch in thickness, are commonly used for these joints. The joint material may be placed at junctions between new concrete and a restraining body such as buildings, curbs, or other kinds of structures. The joint also may be specified for long continuous structures such as ditch linings, and the spacing determined by a professional engineer may vary from 40 to 100 feet. The expansion joint material should be supported and anchored in a uniform plane true to line, and remain in this position while concrete is placed. After completion of the concrete work, the exposed edges of the expansion material should be flush with the concrete surfaces and free from mortar or other concrete material.

FINISHING CONCRETE

The kind of finish specified for concrete work depends on the use of the completed job. The wood float finish is generally adequate. Under certain conditions mentioned below, a trowel or broom finish may be required.

After the concrete has been placed and consolidated, the surface is struck off flush with the forms or finish strips. A 2 x 4 or 2 x 6 on edge is often used on small jobs. The striking off, or screeding, is a leveling operation that removes humps and carries excess concrete ahead of the screed to fill the hollows and give a true surface. In the screeding process some tamping action may be necessary to embed large aggregate and to bring a very small amount of mortar to the surface. Light floating, as required to give a uniform surface, follows the screeding.

The final finish is delayed until the free water has disappeared and the concrete surface takes on a dull appearance.

When excess water is present on the surface, the final finishing should be delayed until evaporation has taken place. Dry cement should not be applied to take up moisture or water added to the surface to aid in finishing. Such practices alter the mix and may cause cracking, dusting, spalling, or other surface deterioration.

The wood float results in a relatively smooth surface with a sandy texture. When a dense smooth surface is desired, the steel trowel or float should be used after the surface becomes quite firm. Concrete should not be troweled when soft and plastic, and the troweling operation should be limited to the minimum required for a smooth surface. Better traction and a pleasing appearance may be added to a trowel surface by lightly brushing with a broom.

Magnesium metal floats and trowels have been found to give a superior finish when air-entrained concrete is used.

FORM REMOVAL

Forms should not be removed from a structure until the concrete has hardened adequately to prevent surface damage, and sufficient strength exists to safely support any loads that may be applied. When the average daily temperatures are above 50° F., forming for sidewalls and tops of sloping surfaces can usually be safely removed 24 hours after the concrete is placed. When the concrete temperatures approach 32° F., additional time should be allowed for the concrete to harden.

Forming that provides vertical support, such as inside of barrels, slabs or arches, should remain in place until the concrete has developed adequate strength to support the weight of the concrete and any live loads that may occur. The minimum lapse time before removing this type of forming should be as specified on the drawings, or the strength of the concrete as determined from test cylinders.

Precaution should be taken to remove all forms with the minimum amount of stress or shock to the structure. Pry bars or other metal tools should not be placed against the concrete to loosen the forms. Wooden wedges driven between the form and the concrete and tapping of the forms should be sufficient effort to remove forming that has been properly constructed, cleaned, and coated with form oil.

REPAIR OF CONCRETE

Minor surface defects such as snap tie cone depressions, small honeycomb areas, or broken corners or edges are generally repaired with a dry-pack mortar. The repair will develop the best bond if applied immediately after stripping the forms and while the concrete is green.

All loose questionable concrete should be removed and the area to be repaired should be washed clean. The total area in contact with the mortar should be kept moist for at least 1 hour prior to making the repair.

Dry-pack mortar consists of a mix of 1 part cement and 2-1/2 parts of sand that will pass a No. 16 screen. Only enough water should be added to produce a filling which is at the point of becoming rubbery when the material is solidly packed. Excess water in the mix will cause shrinkage and a loose repair.

The repair should be placed in layers less than 1/2 inch in thickness. Additional layers may be placed without delay unless the patch material becomes rubbery. For small depressions such as snap tie holes, each layer should be compacted by using a hardwood tamping stick and working at a slight angle toward the sides of the area to be filled. The surface of the repair should be made just flush with the adjacent concrete.

The repaired areas should be cured in the same manner as originally required for the structure. If curing compound is not applied upon completion of the work, the repaired surfaces should be kept wet for at least 24 hours to prevent shrinkage.

CURING CONCRETE

Proper curing increases strength, durability, and watertightness of concrete.

Adequate curing methods accomplish two important functions:

1. Retain sufficient moisture within the concrete to permit complete hydration of the cement.

2. Stabilize temperatures at the level required to complete the chemical reaction.

The ideal curing temperature for concrete is about 70° F. All new concrete should be maintained above 40° F. for at least 3 days. Concrete treated with proper curing methods and maintained at satisfactory temperatures will attain approximately 70 percent of the 28-day design strength in 7 days.

Recommended curing methods include:

1. Water - spraying, fogging, or ponding.

2. Covering - with wet burlap, canvas, sand, or other material.

3. Membrane compounds - sprayed or painted on concrete surfaces to prevent evaporation of water from the mix.

Curing with water requires that the exposed surfaces are kept wet for the duration of the curing period, usually a minimum of 7 days. Water should be applied immediately after finishing and when the concrete has taken initial set. Flowing water should not come in contact with newly placed concrete. Forms should be removed as soon as possible so that curing procedures can be performed. When form removal is delayed, water should be added to the exposed concrete surface and allowed to penetrate along the formed surface, or by covering the forms with burlap or canvas and wetting the material for the required curing period.

Membrane compounds have become widely used curing aids because of their ease of application. The compounds are available in clear, black, white, or gray. White or gray pigmented compounds are preferred because of the ease of determining coverage of the surface and the reflection of heat rays which reduce concrete temperatures in hot weather. It is very important to have complete uniform coverage of all the concrete surfaces. The compound should be well mixed and applied with a spray at a rate of 1 gallon per 150 square feet of surface. If the coating is damaged by heavy rain or by other cause during the curing period, the surfaces should be recoated. The compound should be applied to exposed surfaces immediately after the concrete is finished and the free water has evaporated. If there is any delay, the surface should be kept moist with water until the compound is applied. After the forms are removed the surfaces should be kept wet until necessary surface repairs are made, and then the curing compound should be applied. Curing membranes prevent satisfactory bond of the concrete; therefore, it is very important to determine that the curing compound is not applied to surfaces requiring bond, such as construction joints, surfaces requiring repair, reinforcing steel, or other embedded items.

REQUIREMENTS FOR HOT WEATHER

Hot weather increases the rate of evaporation of the mixing water and the temperature of the mix. Too rapid setting or drying out of the concrete, which often occurs during high temperatures, can result in a badly cracked surface, flaking, and shrinkage. These generally cause a weakened, inferior concrete.

Hot weather precautions become necessary when temperatures are above 85° F. The following basic steps should be taken to obtain good quality concrete in hot weather:

1. Reduce the temperature of the mix by prewetting the aggregates, adding ice to the mixing water, or by making evening or early morning pours when temperatures are more favorable.

2. Saturate the subgrade sometime in advance and sprinkle subgrade and forms just ahead of placing concrete.

3. Prevent overmixing and delays in placing concrete.

4. Have adequate help so that finishing can be accomplished rapidly.

5. Start curing as soon as possible.

If temperatures are extreme it is desirable to water cure the finished surface for at least 12 hour prior to coating with membrane compound.

REQUIREMENTS FOR COLD WEATHER

Concreting in cold weather requires precaution in mixing, placing, and curing. Concrete gains strength slowly at temperatures below 50° F., and can be seriously damaged by freezing and thawing at an early age. Concrete must be protected in cold weather to provide a suitable curing temperature. Plans and equipment for protecting the concrete should be scheduled in advance, and the equipment should be on the job prior to placing concrete.

Concrete should not be placed when the minimum daily temperature is less than 40° F., unless facilities are provided to prevent freezing. Concrete at the time of placing should be in the temperature range of 50° F. to 90° F. Heating the mixing water is a common method of increasing the temperature of the mix. The mixing water should not come in direct contact with the cement when the water temperature exceeds 100° F. Excessive heat in the mixing water or aggregates can cause flash set when they make contact with the cement.

Concrete should not be placed on frozen subgrade. All ice and snow should be removed from inside the forms and from around the reinforcing steel.

Cold weather curing requires suitable temperatures and moisture conditions for the concrete to promote strength and to prevent freezing. The concrete may be protected by covering, insulating, or housing. The amount and kind of protection will depend on the weather conditions and the type of structure. Concrete generates heat for the first few days, and when temperatures are not severe, covering with hay, straw or insulating blankets when kept in close contact with the concrete may provide adequate protection.

For large structures or when temperatures are quite severe there is need for housing and a source of dependable heat. The concrete surfaces should be maintained at not less than 50° F. for the specified curing period. When dry heat is provided, it is necessary to add moisture to the air within the enclosure, or apply wet cure to the concrete.

Acceleratora or antifreeze compounds such as calcium chloride should not be used.

It is desirable to maintain complete records of weather conditions and temperatures when placing concrete in cold weather. It is also desirable to have daily maximum and minimum temperatures of representative surfaces of the concrete structure for the duration of the curing period.

FORM CONSTRUCTION

Materials

Wood and metal are suitable for concrete forms. Concrete-form-grade plywood sheathing and 2 x 4 studs and wales make the best combination. When plywood sheathing is not available, shiplap or tongue-and-groove lumber may be used. Such form lumber should be finished on all 4 sides and free of knotholes and decay. Double forms for walls or other sections require adequate ties and spacers. Form snap ties which are available from commercial supply are commonly used, due to the ease of assembly and saving in labor. These patented steel rods act as spacers to give the desired concrete section, and also provide a dependable tie to hold the forms in position and resist the concrete loads. After the forms are removed, the excess length of the tie rod should be removed by twisting, which results in a break at a predetermined point slightly within the concrete wall surface. The small recess in the concrete caused by the rod and cone is filled with mortar. Threaded bolts and screw assemblies are also available for extra heavy load requirements.

Fabrication Requirements

All forms must be strong enough to contain and support the concrete while it is plastic, and to carry the live loads incidental to the construction operation. They also must be tight to prevent the escape of the water-cement paste from small openings, which could result in honeycomb or sand streaking. The forms also have to be constructed to correct dimension and securely braced and anchored to form the shapes and surfaces specified in the drawings.

Forms should be inspected prior to placing concrete to verify the dimensions, grades, and adequate strength. Freshly mixed concrete exerts great pressure and presents a serious problem if forms bulge or fail during the pouring operation.

Form Design

Detailed design of concrete forms requires the analysis of the loads and pressures exerted by the concrete and the selection of materials that may be used to withstand the loads (see Table 17-1).

Table 17-1 Concrete pressure per square foot of form *

	Rate of pour (feet of height per hour)						
	2	3	4	5	6	8	10
Maximum pressure in pounds per square foot at:							
50° temperature	520	690	860	1,030	1,210	1,470	1,580
70° temperature	400	520	630	750	860	1,090	1,170

* This table is based on the use of mechanical vibration inside the forms.

The selection of form material and the proper spacing for studs, wales and form ties have been presented in curves and charts by numerous form and form accessory manufacturers. Table 17-2, duplicated through the courtesy of Superior Concrete Accessories, Inc., is typical and provides a quick reference that may be used in checking the adequacy of concrete forming.

The use of Table 17-2 is illustrated by the following problem.

Determine the required spacing of the studs, wales, ties, and the unit load per tie where the following conditions are known:

1. Sheathing - 3/4-inch plywood; studs 2 x 4; wales double 2 x 4.
2. Rate of pour - 4 feet of wall per hour.
3. Setting temperature of the concrete - 70° F.

Table 17-2 is based on a setting temperature of 70° F. (meeting condition 3). In the table, columns are given for rates of pour varying from 2 to 10 feet per hour. Column 3 shows the correct spacing of studs, wales and ties for a rate of 4 feet per hour (meeting condition 2). Thus, by reading down this column and under the heading of "lumber sizes" and "spacing of studs" and opposite "3/4-inch sheathing" we find the required spacing for the studs to be 18 inches; continuing under the heading "wale spacing" and 2 x 4 studs, the spacing of the wales is 28 inches, and under "tie spacing" opposite double 2 x 4 wales, the spacing of the ties is 24 inches.

The total load per tie is obtained by multiplying the maximum pressure per square foot, 630 pounds (shown top of column for 4-foot rate) by the area supported by the tie rod. Thus, 630 pounds x 2.33 feet (spacing of wales) x 2.0 feet (spacing of ties) = 2,935.

The total computed load per tie for the suggested forming is within the safe working limits of a 3/8-inch form tie which has a safe load of 3,000 pounds and an ultimate capacity of 4,500 pounds.

Method of Assembly

The method of assembly commonly used for forming small structures is shown in Figure 17-1. The forms should be constructed so that they can be easily filled and removed. All forms should be adequately nailed and braced. Double-headed form nails are commonly used for exterior nailing since they expedite the removal of the forms and also increase the salvage of the form materials.

Treatment of Surfaces

Form surfaces that will be in contact with the concrete should be painted with some type of oil or sealant that will prevent the concrete from sticking to the forms. Surface treatment also aids in preventing the forms from warping. Materials specially prepared for coating forms may be purchased; however, for small jobs engine lubricating oil or used oil may be substituted. Lubricating oil may be thinned with kerosene as required for easy brushing. Excess surface coatings should be removed from the forms. Any coating material must be removed from the reinforcing steel or surfaces of concrete to be in contact with the new pour. Forms should be cleaned and oiled each time they are used.

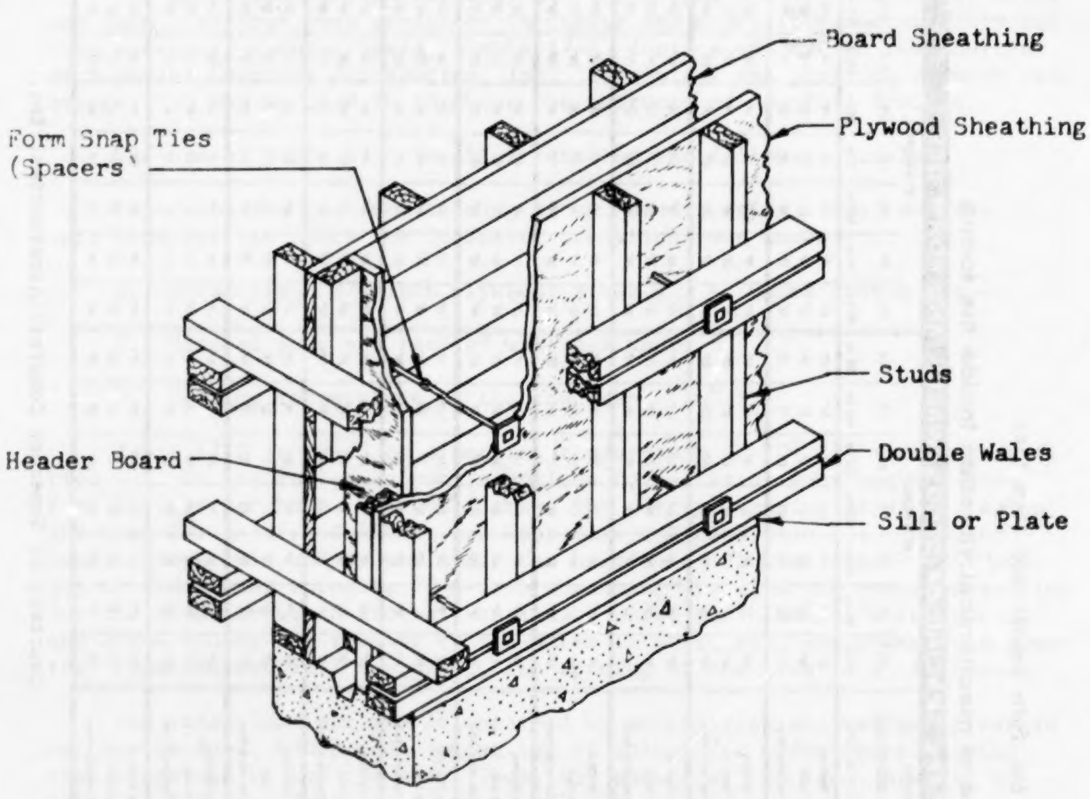
Table 17-2 Spacing data for form lumber and form ties

These tables are based on the use of mechanical vibration inside the forms

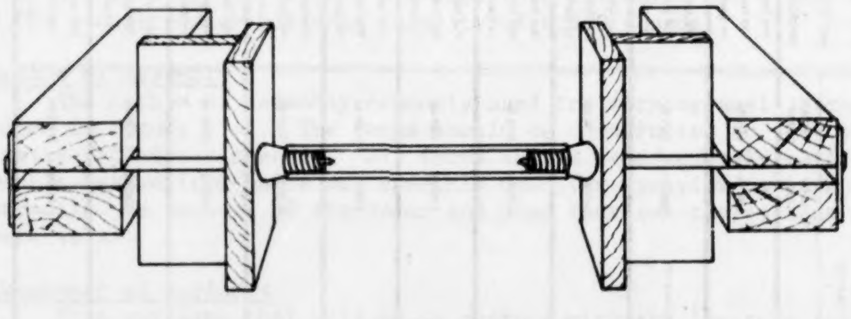
LUMBER AND FORM TIE DATA				SAFE SPACING OF STUDS, WALES, AND FORM TIES														
LUMBER SIZES	FORM TIES			POURING TEMPERATURES	50° FAHRENHEIT							70° FAHRENHEIT						
	TYPE	SAFE LOAD	ULTIMATE CAPACITY	RATE OF POUR — FT. OF HEIGHT PER HOUR	2 Ft.	3 Ft.	4 Ft.	5 Ft.	6 Ft.	8 Ft.	10 Ft.	2 Ft.	3 Ft.	4 Ft.	5 Ft.	6 Ft.	8 Ft.	10 Ft.
				CONCRETE PRESSURE PER SQ. FT. OF FORMS	520 lbs	690 lbs	860 lbs	1030 lbs	1210 lbs	1470 lbs	1580 lbs	400 lbs	520 lbs	630 lbs	750 lbs	880 lbs	1090 lbs	1170 lbs
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 4 STUDS 2 - 2 x 4 WALES	3M Snap Ties A. C. Ties No. 2 Rod Clamps with ⅜" Plain Rods	3,000 lbs	4,500 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	30"	27"	26"	24"	23"	22"	22"	31"	30"	28"	27"	26"	24"	23"
				Tie Spacing for Safe Value of Ties and/or Wales	27"	23"	19"	17"	15"	13"	12"	32"	27"	24"	21"	19"	18"	16"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 4 STUDS 2 - 2 x 4 WALES	5M* Snap Ties Superties* Tilt Locks with ½" cold rolled rods No. 3 Rod Clamps with ½" Plain Rods	5,000 lbs	7,500 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	30"	27"	26"	24"	23"	22"	22"	31"	30"	28"	27"	26"	24"	23"
				Tie Spacing for Safe Value of Ties and/or Wales	30"	28"	26"	25"	23"	22"	20"	32"	30"	29"	27"	26"	25"	24"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 4 STUDS 2 - 2 x 6 WALES	5M* Snap Ties Tilt Locks with ½ cold rolled rods No. 3 Rod Clamps with ½" Plain Rods	5,000 lbs	7,500 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	30"	27"	26"	24"	23"	22"	22"	31"	30"	28"	27"	26"	24"	23"
				Tie Spacing for Safe Value of Ties and/or Wales	45"	38"	32"	29"	25"	22"	20"	50"	46"	40"	35"	32"	27"	26"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 4 STUDS 2 - 2 x 6 WALES	½" Coil Ties	6,000 lbs	9,000 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	30"	27"	26"	24"	23"	22"	22"	31"	30"	28"	27"	26"	24"	23"
				Tie Spacing for Safe Value of Ties and/or Wales	51"	48"	38"	34"	31"	28"	25"	50"	50"	46"	43"	38"	33"	32"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 6 STUDS 2 - 2 x 6 WALES	½" Coil Ties	6,000 lbs	9,000 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	45"	42"	40"	38"	36"	34"	34"	49"	46"	44"	42"	40"	38"	36"
				Tie Spacing for Safe Value of Ties and/or Wales	38"	30"	25"	22"	19"	17"	16"	44"	38"	31"	27"	25"	21"	20"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 6 STUDS 2 - 2 x 6 WALES	½" and ¾" Coil Ties Tilt Locks with ½" cold rolled tie rods	9,000 lbs	13,500 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	46"	42"	40"	38"	36"	34"	34"	49"	46"	44"	42"	40"	38"	36"
				Tie Spacing for Safe Value of Ties and/or Wales	43"	38"	35"	33"	30"	28"	24"	47"	42"	39"	38"	35"	33"	32"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 6 STUDS 2 - 3 x 6 WALES	½" and ¾" Coil Ties Tilt Locks with ½" cold rolled tie rods	9,000 lbs	13,500 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	46"	42"	40"	38"	36"	34"	34"	49"	46"	44"	42"	40"	38"	36"
				Tie Spacing for Safe Value of Ties and/or Wales	52"	45"	38"	33"	32"	28"	24"	57"	52"	46"	41"	37"	31"	30"
2" (1⅝") SHEATHING 3 x 6 STUDS 2 - 3 x 6 WALES	½" and ¾" Coil Ties Tilt Locks with ½" cold rolled tie rods	9,000 lbs	13,500 lbs	Stud Spacing for Safe Value of Sheathing	40"	37"	34"	32"	30"	28"	27"	44"	40"	38"	35"	34"	31"	31"
				Wale Spacing for Safe Value of Studs	42"	38"	35"	33"	32"	30"	29"	45"	42"	39"	37"	34"	33"	32"
				Tie Spacing for Safe Value of Ties and/or Wales	41"	37"	35"	33"	31"	29"	29"	45"	39"	38"	37"	36"	32"	31"
1" (25/32") SHEATHING or 5/8" PLYWOOD 2 x 6 STUDS 2 - 2 x 6 WALES	¾" Coil Ties	12,000 lbs	18,000 lbs	Stud Spacing for Safe Value of Sheathing	20"	18"	16"	15"	14"	13"	12"	23"	20"	18"	17"	16"	14"	14"
				Wale Spacing for Safe Value of Studs	46"	42"	40"	38"	36"	34"	34"	49"	46"	44"	42"	40"	38"	36"
				Tie Spacing for Safe Value of Ties and/or Wales	42"	38"	35"	33"	31"	29"	28"	47"	42"	39"	37"	35"	31"	31"
2" (1⅝") SHEATHING 3 x 6 STUDS 2 - 3 x 6 WALES	¾" Coil Ties	12,000 lbs	18,000 lbs	Stud Spacing for Safe Value of Sheathing	40"	37"	34"	32"	30"	28"	27"	44"	40"	38"	35"	34"	31"	31"
				Wale Spacing for Safe Value of Studs	42"	38"	35"	33"	32"	30"	29"	45"	42"	39"	37"	34"	33"	32"
				Tie Spacing for Safe Value of Ties and/or Wales	41"	37"	35"	33"	31"	29"	29"	45"	39"	38"	37"	36"	32"	31"

*Ultimate Capacity 7,000 lbs.

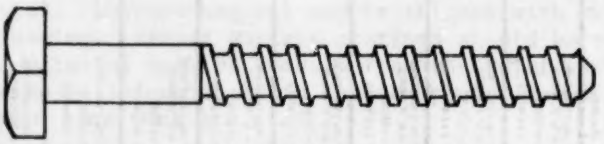
Courtesy of Superior Concrete Accessories, Inc.


Board Sheathing
Plywood Sheathing
Form Snap Ties (Spacers)
Studs
Header Board
Double Wales
Sill or Plate

AN EXAMPLE FOR BUILDING FORMS FOR SMALL STRUCTURES



MALE BOLT TYPE FORM AND SPREADER TIE



MALE BOLT

Figure 17-1 Typical form assembly

5. STEEL REINFORCEMENT

PURPOSE

Steel reinforcement is embedded in concrete to increase its strength in tension. The tensile forces may result from loading imposed on the structure or from temperature stresses.

MATERIALS

Kinds

The kinds of steel reinforcement commonly used for concrete are deformed bars and welded wire fabric.

Quality

The quality of the steel reinforcement is of major importance for all structures. Only steel products manufactured by standard plant control procedure and meeting the design requirements should be used. The use of scrap iron, cable, woven wire or other waste metal is unsatisfactory.

Size

Deformed round steel bar reinforcement is manufactured in sizes of 3/8 inch to 1-3/8 inches in diameter and square bars of 1-1/2 and 2 inches. The diameter or size of the round bars is shown on the bar by a number. The number designates the diameter in terms of multiples of 1/8 inch, for example #3 = 3/8-inch diameter, #7 = 7/8-inch diameter. This method of size designation is used for bar sizes of #2 (plain bar) through #11.

Wire fabric is designated by the spacing of the longitudinal and transverse strands and the size (gage) of steel wire. A designation of 612-25 (one way type) indicates that the longitudinal wires are spaced 6 inches; the transverse wires at 12 inches; the gage of the longitudinal wire is 2; and the transverse wire is 5 gage.

Square welded wire fabric may be designated as follows: 6x6-8/8 which indicates a 6-inch spacing of the wires and 8-gage diameter for each wire.

Onsite Storage

Steel reinforcement that is not to be used for an extended period should be stored off the ground and protected from the elements. Steel that is delivered to the site for use within a short period should be stored to prevent surface contamination with mud or other coatings. Piling on the ground is permissible under dry conditions. At the time of placement in the structure, the steel should be free from oil, grease, mud, paint, loose mill scale, and flaky rust coatings. A thin adhering coat of rust is not considered to be detrimental to bond.

BENDING DRAWINGS

The drawings prepared for the job should include a steel list and bending chart which shows the various bars by a designated letter or number, the size, number of bars required, location in the structure, and the dimensions for cutting and bending. If steel is purchased from a fabricating plant in cut and bent form, the plant will make the required bends, hooks, spirals, etc., according to accepted standards of the industry. The fabricator will itemize the steel list by bar designation, number of pieces, length, and usually will indicate the location the bar is to be placed in the structure.

Steel bent on the job should be formed to meet tolerances established by industry. For 90° and 180° bends and hooks the arc of the bend should be formed around a pin that is 6 times the bar diameter for #2 through #7 bars, and 8 bar diameters for bars #8 through #11.

All bent reinforcing steel should be inspected for cracks or other indications of stress that might reduce the tensile strength of the steel.

PLACING

Positioning

Accurate positioning of the reinforcing steel within the concrete is important. Steel required to resist structural stress must be placed in the location shown on the drawings. The proper location can vary depending on the kind of structure. Typical illustrations of steel location to resist stresses in structures is shown in National Engineering Handbook Section 19, Chapter 3.

Coverage

The specified limits of cover for all the steel as shown on drawings should be adhered to. Reinforcement steel for structural stresses is usually placed near one face of the concrete. The minimum cover is measured from the form or ground to the reinforcing steel and is measured in the clear.

Laps

Stress in a tension bar can be transmitted through the concrete and into another adjoining bar by a lapped splice. The amount of required lap is expressed as the number of bar diameters. The minimum lap usually will not be less than 24 diameters.

EMBEDDED ITEMS

Anchors

Bolts or other items are often required to be placed in the concrete. All embedded items should be placed and anchored prior to placing concrete to insure good bond and proper location. These items should be carefully checked prior to and during the placing of the concrete.

Dowels

Dowels are short steel bars that are installed to extend across an expansion-contraction joint. They are used to give support for grade and alignment between two adjacent segments of concrete. To perform properly, it is necessary that one-half of the bar be bonded to the concrete and the other portion treated to prevent bond with the concrete. The drawings should show the details for installation. Bond may be prevented by coating the steel with tar or heavy wrapping paper. Patented metal or plastic sleeves are also available. Additional clearance is needed beyond the unbonded end of the bar to permit free movement. No steel should extend across a joint of this type unless treated as specified. The dowel assemblies should be properly supported and anchored to maintain position and alignment when concrete is placed.

ANCHORAGE AND SUPPORTS

All steel reinforcement should be accurately located in the forms and firmly held in place during the placement of the concrete. Mats of steel used in slabs and the vertical and horizontal steel placed in walls should be tied with wire ties to form a rigid assembly.

Small precast concrete blocks which have a thickness equal to the required clearance or cover are very satisfactory for supporting mats of steel in slabs and for positioning vertical steel for proper cover. The support blocks should have a strand of the tie wire embedded in the block for use in anchoring the block to the reinforcing bars. For more complex structures the use of spacer bars, wires, chairs, or other devices may be required to prevent displacement of the steel. The use of wood or brick for support or spacing is not allowed.

INSPECTION

Prior to Placing Concrete

All reinforcing steel should be checked against the drawings to determine that the size, length, bends, location, and laps are as specified. The steel should be checked for coatings, sharp bends, or other damage. The steel should be firmly tied and have adequate supports and anchors to prevent movement. The position of the steel should provide the proper amount of cover, and no bars should extend within 2 inches of finish grade.

When wire fabric is used it is very important that the mesh is adequately supported and that the laps and ties are made as specified. Hooks or other methods of lifting the mesh to proper position after the concrete is placed should not be permitted.

While Placing Concrete

Constant attention is required to detect any displacement of the reinforcement and to see that the necessary corrections are made. The position of the vertical steel is often distorted by the placing and vibration of the concrete. Mats in slabs may move as a result of trampling by the workmen.

6. STRUCTURE DRAINAGE AND CONTROL OF WATER

PURPOSE

Structure drainage is required to provide for the relief of water pressures and to permit safe water movement through the foundation area. Control of water at construction sites is necessary to protect the foundation area and to maintain satisfactory construction conditions.

MATERIALS

Sand, Gravel, or Rock

Sand, gravel, or rock materials graded to be free draining (less than 5 percent of material passing the 200-mesh sieve) and blended to give a mixture that will resist soil movement into the drain material may be used to provide drainage for structures. All drain material should consist of dense particles having characteristics similar to the requirements for concrete aggregates. Particles smaller than 1/4 inch should be natural sand.

Perforated Pipe

Materials suitable for perforated drainpipe include corrugated metal, asbestos-cement, bituminous fiber, concrete, plastic or clay. The perforations normally consist of circular punched or drilled holes 1/4 inch to 5/16 inch in diameter, spaced 3 inches apart. They should be arranged in 2 or 4 rows parallel to the axis of the pipe. The individual rows are spaced 90° apart for 2 rows, and 90° and 160° for 4 rows. The length of pipe sections and the kind of joints depend on the pipe material. The more common type of joints includes bands, collars, or bells.

Weep Holes

Weep holes for relieving water pressure through the structure are preferably formed from nonferrous materials such as asbestos-cement, bituminous, clay, concrete, or paper. Pipe containing iron is structurally adequate but is often discouraged because of the rust staining the concrete.

TYPES OF DRAINS

Several types of structure drains are shown in Figure 17-2. Of these, the chimney drain and relief well types are seldom used at the work unit level.

Earth Dams

Toe Drains

Consist of sand and gravel, rock or perforated pipe, and are located in the downstream toe of the dam (Figure 17-2, Toe Drain).

Blanket Drains

Consist of a layer of sand, gravel, or rock placed over a portion of the downstream area of an embankment or the subgrade for a concrete structure (Figure 17-2, Blanket Drain or Wall Drain).

Trench Drains

May consist solely of sand-gravel or crushed rock or they may also contain a perforated pipe which discharges into an outlet. The drain may be located in the downstream foundation area or in the embankment (Figure 17-2, Trench Drain or Chimney Drain).

Concrete Structures

Subgrade Blanket

Structure locations, which involve high water table, commonly require a blanket of pervious material to provide free movement of water. Soft foundation materials may also exist at these locations and the use of blanket materials improves the stability of the foundation. The subgrade drain materials may also extend above the floor slab along the sidewalls to release water through weep holes (Figure 17-2, Wall Drain).

Perforated Drainpipe

This type of drain may be installed within the subgrade or in the drain materials adjacent to the walls to provide added capacity and more positive protection to the structure. Unrestricted outlets are required for the pipe drains.

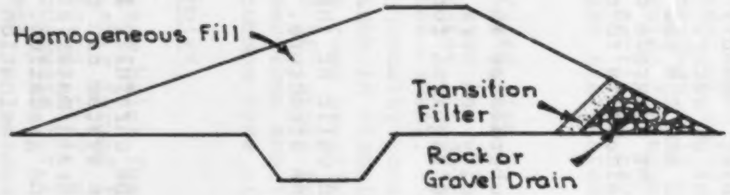
Weep Holes

Weep holes may be installed in the floor slab and walls of the structure as required to provide drainage protection for the structure.

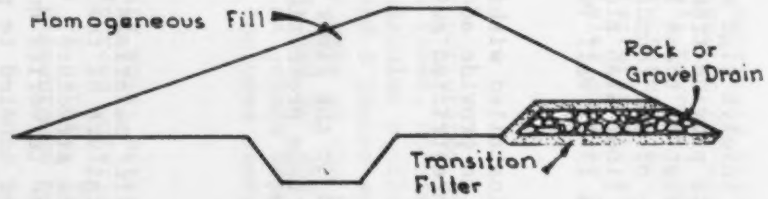
INSTALLATION

Filter Materials

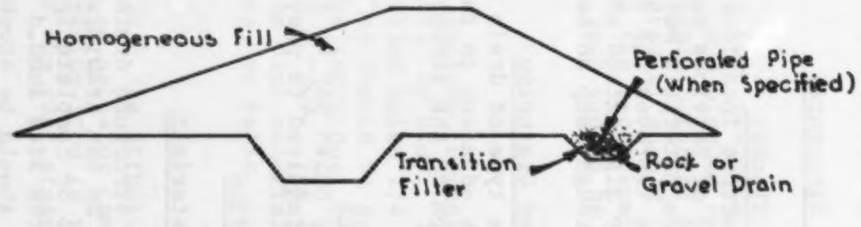
For structure drainage, filter materials should be carefully installed as shown on the drawings. The failure of the drainage system can cause damage to or complete loss of the structure. Filter drain materials delivered to the site should be tested to verify quality and gradation. The material should be stockpiled and handled to prevent contamination with


Homogeneous Fill
Transition Filter
Rock or Gravel Drain

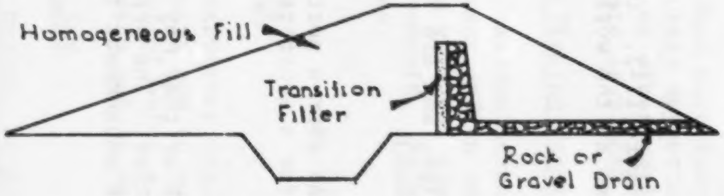
(a) TOE DRAIN


Homogeneous Fill
Rock or Gravel Drain
Transition Filter

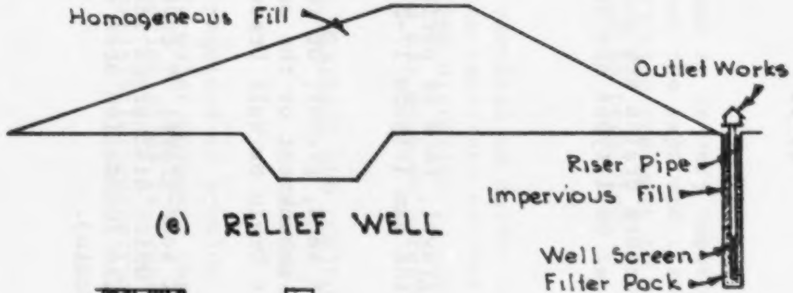
(b) BLANKET DRAIN


Homogeneous Fill
Perforated Pipe (When Specified)
Transition Filter
Rock or Gravel Drain

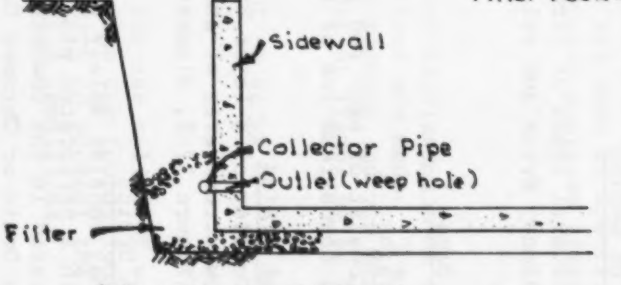
(c) TRENCH DRAIN


Homogeneous Fill
Transition Filter
Rock or Gravel Drain

(d) CHIMNEY DRAIN


Homogeneous Fill
Outlet Works
Riser Pipe
Impervious Fill
Well Screen
Filter Pack

(e) RELIEF WELL


Sidewall
Collector Pipe
Outlet (weep hole)
Filter

(f) WALL DRAINS

Figure 17-2 Type of structure drains

fine grained soils or other material that might impair its ability to function as a drain. The material should be placed by methods that will prevent segregation. When placed in deep excavations or under water the material should be lowered into place, using clamshell buckets, skips or other methods to prevent segregation. The thickness of the layers, surface finish and compaction should conform to the requirements shown on the drawings.

Perforated Pipe

Perforated drainpipe requires care in handling and placing to prevent damage to the pipe or its protective coating. All sections of the pipe should be inspected to make sure the perforations are open. Pipe treated with asphalt coatings requires special attention. The use of a wooden probe shaped to the proper diameter may be used to clear asphalt material from the drain holes without serious damage to the metal coating. During the installation of the pipe, inspection is required to determine that the location, grade, and alignment is as shown on the drawings. Also, see that the pipe is positioned so that the drain openings are symmetrically located at the bottom of the pipe and that the joint connections are tight and made according to the manufacturer's requirements. Pipe enclosed within a filter requires special attention to determine that the line and grade is maintained.

Weep Holes

Pipe material used for forming the weep hole should be cut to proper length and anchored in position prior to placing concrete. The pipe, when so specified, should extend into the filter materials. Hardware cloth or screen materials should be installed in position as shown on the drawings to prevent the entrance of small animals that could hinder operations of the drain. All weep holes need to be checked after construction to see that they are free from obstructions.

SITE DEWATERING AND CONTROL OF WATER

Foundations

Dams and Dikes

Adequate foundation preparation and proper placement of embankment is dependent on a water-free site. Embankments for dams should not be placed in water or on a soft foundation. The first job on a wet site is to remove the water and prevent more from entering the foundation area. The methods may vary with site condition and location. Methods that have application include diversion of streamflow above the site, drainage by gravity using ditches through the site, pumping from trenches or sumps adjacent to the foundation area, and for extreme conditions a system of wells or well points. Some sites are wet only during certain seasons of the year. For such locations it is best to do the construction when the site is dry.

Concrete Structures

The need for dewatering the structure site is important and similar methods used for earth dams may be used effectively. Concrete structures should be installed only on a firm subgrade. Wet areas require control of water to make the necessary excavation, and for placing drain or subgrade materials. All concrete should be placed in the dry. No standing or flowing water should come in contact with the concrete until the mixture is well set up.

Borrow Areas

Borrow areas containing materials suitable for impervious embankment construction require careful moisture control. Excess water within the borrow area, regardless of source, can increase costs and delay the work. Some borrow areas subject to flooding may be protected by diversions and dikes. For certain conditions it may be necessary to lower the water table in the borrow area by pumping. The probability of flooding versus the cost of an alternate borrow area should be considered in the design phase.

Diversions

The construction of a diversion should be given high priority for controlling streamflow that passes through a construction site. The amount of channel capacity required for many locations is economical and the construction is not difficult. If the diversion cannot be routed to completely bypass the construction area, it may be possible to route to a location that results in a greatly improved working area.

7. PIPE CONDUITS

MATERIALS

The manufacture of pipe conduits involves a large variety of materials and processes. Pipe materials that have been determined to meet the minimum requirements for specific practice installations are outlined in National Engineering Handbook, Section 2, Engineering Practice Standards, national engineering memoranda and state supplements to national policy.

A careful review of the reference standards as they apply to the site condition is desirable to insure that the pipe meets the qualifications before installing the materials.

HANDLING AND STORAGE

Pipe should be transported and unloaded by methods that will prevent damage to the pipe or the surface coating. Pipe should not be permitted to "free fall" from trucks, or be lifted by means of a sling running through the pipe. If the coatings are damaged, the affected areas should be cleaned and coated with zinc paints or cold tar materials as recommended by the pipe manufacturer.

Pipe should be stored near the site to eliminate extra handling. Piling or decking in ricks should not be permitted. Paved invert pipe should be stored with the paved area at the bottom. All pipe should be inspected prior to installation. Materials that are damaged or otherwise fail to meet specifications should be rejected.

INSTALLATION

Trenching

Earth Excavation

Excavation for pipelines should be to the lines and grades shown on the drawings with adequate checks made to verify the accuracy of the cut. Vertical wall trenches in most materials are a safety hazard when depths exceed 4 feet. Adequate shoring or a suitable movable shield should be provided to protect workmen while laying pipe.

Rock Excavation

Excavation in rock should be made to the limits shown on the drawings. It is common practice to overexcavate the depth to provide space for fine grained subgrade material used as bedding for the pipe. It is important that the rock excavation be checked to make sure no high spots exist.

Bedding

Earth

Bedding formed in earth requires that the subgrade be molded to a specific depth to fit the outer surface of the pipe. The pipe should bear against undisturbed or compacted earth for its entire length. For corrugated pipe, use a loose mellow bedding material about 2 inches thick.

Granular Material

Bedding formed from granular material requires the placing of sand, gravel or crushed rock to a specified depth in the bottom of the trench. The granular material should be consolidated, and shaped to fit the outer surface of the pipe for its entire length.

Concrete Bedding

The bottom of the trench should be shaped as shown on the drawings, and the concrete thoroughly tamped or vibrated around the bottom of the pipe. The pipe may be supported on concrete blocks, when so required, to provide additional thickness of the bedding. Care is required in placing concrete to prevent lifting or displacing the pipe.

Concrete Cradles

Pipe cradles consist of complete or partial encasement of the conduit. The dimensions and other details for construction should be shown on the drawings. It is necessary to support the pipe, to proper line and grade, on precast or poured concrete blocks. Concrete should be placed on either side of the conduit in approximate equal amounts. Care is required in consolidating to make sure concrete makes complete contact with the pipe and that the pipe remains in correct position.

Jointing

Premolded Gasket

Bell and Spigot--It is common procedure to lay bell and spigot pipe with the bell upstream. Holes are excavated in the subgrade to receive the bell and eliminate uneven pressure. Just before making the joint, the surfaces of the bell and spigot should be cleaned and lubricated with a light film of vegetable compound. The premolded rubber gasket should be stretched uniformly as it is placed in the spigot groove. The joint is connected by a pulling or jacking force applied so that the spigot enters squarely into the bell. When the jointing is nearly complete the position of the rubber gasket is checked with a feeler gage to make sure the gasket is properly positioned; then the spigot is completely pulled into position.

Sleeve Joints--Conduits jointed by the use of sleeves or collars include all pipe ends formed as spigots with the sleeve connector acting similar to a bell. Prior to jointing, all surfaces and rings are cleaned and lubricated as required for bell and spigot pipe. One end of the sleeve or collar may be installed prior to placing the pipe in the trench. Final jointing is accomplished as for bell-type conduits.

Cement Mortar

Bell and Spigot--Cement mortar for joints and bands is mixed in the proportion of one part portland cement to two parts sand and sufficient water to produce a workable mix.

The pipe joint surfaces should be clean and moist. Sufficient mortar is added to the lower portion of the pipe bell to make a smooth inner surface. The spigot end then is completely jointed. The remaining annular space between the bell and spigot is completely filled and dressed off with the outside surface of the bell. The interior joint is filled and pointed to a smooth surface. A swab may be used to finish the interior surface of small diameter pipe.

Tongue-and-Groove--The jointing surfaces of the pipe should be clean and moist. The pipe is placed on end with the groove (female end) up. After the groove is covered with mortar the pipe is carefully shoved over the tongue end of the pipe previously laid. Surplus mortar should appear on the interior and exterior surfaces of the joint, indicating that the mortar completely fills the joint. Surplus mortar is carefully removed after the pipe is placed to line and grade.

Banding--External bands of mortar are added to the newly installed pipe to increase the watertightness of the tongue-and-groove joint. The area to be covered should be clean and moist. Sufficient mortar is placed on the ground under the end of each pipe as it is laid to make a continuous band.

Banding operations usually follow 3 to 5 joints behind the laying operation to prevent movement and damage to the band. The banding mortar is shaped and pressed into place by hand. A brush or light trowel finish may be added as required.

Curing--All external mortar joints, bands or collars should be protected by covering with moist earth, sand or burlap and kept moist for the specified curing period, normally 3 days. Backfilling or hydrostatic pressure should not be applied to the pipe until approval is given.

Welding

Steel pipelines may be joined by welding. The pipe should be uniformly round with smooth end surfaces so that a tight butt weld can be made. The surfaces to receive the weld should be free of all coatings. The welder should be qualified and have all necessary equipment to perform the work. The pipe should be so positioned and supported that the weld can be performed without turning or rolling the pipe while welding. The current, arc length, angle and travel speed should be governed to produce a smooth, uniform, well-formed bead. No undercutting, overlapping or piling up is permitted. The completed pipeline should be pressure tested to insure satisfactory workmanship before accepting the work.

The surface of the welds and all damaged coatings are treated with paints and wrappings to provide protection that meets the requirements specified for the work.

Bolted Couplers

Metal pipelines may be joined by bolted assemblies. The most common couplers for smooth metal pipe are flanges and Dresser type units. Flanged ends are attached to the pipe at the factory and can be easily bolted in the field to form a watertight, high pressure joint. Good quality gaskets should be used and all bolts uniformly tightened but not overstressed.

The Dresser coupling includes flanges and gaskets that provide a watertight pressure joint, and also permits limited movement of the pipe within the joint. This patented joint is often specified at predetermined intervals on lines having rigid joints to permit movement caused by temperature or other causes. The end of the pipe to be joined should be uniform in shape and free from all coatings. The coupling is assembled according to the instructions of the manufacturer and uniform tension applied to all assembly bolts.

Corrugated metal pipe is joined by coupling bands which may be manufactured with angle iron bolt type assemblies or rolled bands tightened with rod lug type tighteners. The pipe ends to be joined should be spaced as required to permit the grooves in the band to properly seat into the grooves of the pipe. Tapping the band with a hammer during the tightening process will aid in seating the band. When rubber gaskets are specified, extra care is required to properly position the gasket and the band to form a watertight joint.

Open Joints

Not all pipelines require watertight joints. Concrete and clay pipe used for drainage is laid with open joints. Tongue-and-groove and square end joints are the most common type. The pipe should be uniformly bedded and laid to provide a small space between adjoining sections to permit free entrance of water. The joint gap and cover protection should be installed in accordance with the requirements shown on the drawings.

Backfill

Quality of Materials

Backfill placed in contact with the pipe should consist of select material free from organic material, frozen clods, and rock which exceed 2 inches in diameter. Random material, which may include larger stone, may be used after the specified cover is in place.

Placement

Special care is required in lowering and placing backfill around pipe conduits. This usually requires hand labor to maintain equal fill on either side of the pipe to prevent displacement. Heavy equipment may be used to complete the placement of uncompacted backfill. Surplus material is added to the surface area of the trench location to compensate for future settlement.

Compaction

The requirements and limits for compacted backfill should be clearly outlined on the drawings. Backfill compacted to a specified density will require inspection of the quality of the material, the moisture content, and the in-place density. Backfill for conduits constructed in conjunction with water impounding embankments requires special attention due to the hazard of water movement along the conduit. Precaution should be taken to prevent the lifting or changing of alignment of the conduit during compaction.

8. WATER CONTROL GATES AND VALVES

KINDS

Slide Gates

Slide gates are made for a wide range of sizes and operating heads. The cast iron, steel, or fabricated steel gate assembly consists of a movable slide, which may be round, square, or rectangular in shape, and a connecting stem with an attached geared wheel or crank for opening and closing the slide. The slide is held in position by angle iron or other framework. Wedge blocks are properly positioned to cause the slide to make contact with a stationary frame which provides a watertight closure. Slide gates are manufactured for seating heads varying from 5 to 100 feet. They are used for control of water in storage reservoirs, canals and stream diversion, and on-farm irrigation distribution systems.

Flap Gates

Flap gates are used to control flow automatically. They are used to prevent backflow through pipes under dikes and levees, yet permit drainage at low tide or streamflow stages. The cast iron, steel or fabricated steel assemblies are available in various sizes and shapes. The assembly consists of a gate hinged at the top or upper quarter and a matching seat that forms a watertight closure. The seat may be attached to the pipe or installed as an integral part of a concrete headwall.

Irrigation Control Gates

In addition to the standard low head slide gates commonly used, there are various other types and kinds of products used to control the flow of irrigation water, such as metal turnouts and alfalfa gates. These assemblies may be attached to metal or concrete pipelines, concrete control structures, or concrete ditch linings.

High Pressure Valves

High pressure valves are commonly used to control large flows or high pressure streams. This type of valve usually is of a gate or globe type design. These valves require quality material and finish, and the cost is relatively high. They do not have widespread use in small installations, but may be included in sprinklet systems or high pressure water systems.

Low Pressure Valves

Low pressure valves include the washer and ball seat type and low head varieties of gate valves. They are used in farm irrigation systems and on individual lines in house or other building installations.

QUALITY AND ACCEPTANCE

Standard Brand Names

Acceptance based on detailed specifications and tests is not widely used for small projects. Requirements usually can be dictated by specifying a brand and model "or equal" to illustrate acceptable quality. This procedure is effective for projects financed by the individual owner.

For contract construction involving federal funds the required purchase of specified brand names is not acceptable under present policy. Brand names mentioned in the contract can only denote a reference of quality and workmanship, and other products determined to be of equal quality may be furnished by the contractor.

Reference Specifications

Manufactured materials commonly used in construction are controlled and tested by procedures subscribed to by industry. The quality of the individual materials and performance tests are outlined in references such as "American Society for Testing and Materials" (ASTM), "Federal Specification," "American Water Works Association" (AWWA) and many others common to a specific type of industry. For construction that requires materials of controlled quality, it is general procedure to include in the specifications or on the drawings a request that the product be manufactured to meet the requirements of a specific reference specification.

Manufacturer's Certification

The requirement that the contractor or supplier furnish a certified certificate that the materials meet the requirements set forth for the work may be included when deemed necessary by the Service. The advantage of the certification is to have a record showing that the supplier met the requirements.

Visual Inspection

All materials delivered to the construction site should be inspected. A certification of quality does not insure against damage during handling and transportation. A thorough knowledge of the reference specification and a detailed examination, including applicable measurements and superficial finish, are important parts of construction inspection.

ONSITE HANDLING AND STORAGE

Gates and valves should be handled in a manner to prevent bending, warping, chipping of machined surfaces, damage to surface coatings or other treatment that would prevent proper functioning. Heavy duty slide gates should not be further disassembled on the job without approval of the manufacturer, since factory adjustments are difficult to duplicate in the field. All parts and assemblies should be stored off the ground. All parts should be accounted for on delivery and adequately protected from the elements and loss.

INSTALLATION

Anchor Bolts

Metal anchor bolts positioned in the concrete often are required to hold gate assemblies in place. The manufacturer of the gate should provide a detailed drawing or template for use in positioning the bolts in the form. If the gate or valve assembly is on the job, it is recommended that the bolt setting be carefully checked with the actual gate. To prevent delay and additional cost, all anchor bolts should be placed at the exact spacing and depth specified. Bolts positioned in the forms need to be anchored to maintain alignment when the concrete is placed. Bolts embedded in unformed concrete require that the concrete be consolidated near the bolts to form a good bond.

Field Assembly

Valves

Valves are attached to provide a watertight connection, usually by means of threads or bolted flange connections. Care is required to prevent overstressing the assembly by using excessive wrench pressure while tightening. Bolted flange connectors should contain a thin gasket between the flanges. The individual bolts should be tightened uniformly and only as required to prevent leakage.

Slide Gates

Slide gates are attached to metal pipe, concrete headwalls, embedded metal spigots, or precast metal wall frames (thimbles). Gates designed for high heads usually are installed with some type of thimble. The thimble should be anchored in place and properly embedded in the concrete. The use of a thimble is desirable since it provides matched units and permits attaching the gate assembly at a later date. The contact surfaces of the thimble and the gate are machined; however, it is a good practice to use a gasket or mastic as recommended by the manufacturer to form a positive watertight connection. The anchor studs that hold the gate should be uniformly tightened, being sure not to overstress the studs.

Automatic Flap Gates

Flap gates are attached to concrete walls or to pipe, similar to slide gates. The gate seating face should be installed with the face in a vertical plane or with the bottom of the seating surface projecting slightly forward. The proper positioning of the seating surface is important for proper performance of the gate.

Concrete surfaces to receive a flat back type seat casting should be smooth and true to line. Anchorage to an uneven surface can damage the casting.

After complete assembly, the gate should be checked to make sure the hinges are adjusted to permit uniform contact with the seating surface.

Adjusting and Testing

In addition to proper assembly of the gate, it is important that the hoist be placed in correct alignment with the gate and that the gate stem and guides are adjusted to permit free movement. The gate should be raised and lowered throughout its full range and adjustments made, as required, to permit smooth operation free from unusual resistance or binding.

OPERATION AND MAINTENANCE

Overstressing

It is important that undue effort is not exerted in opening and closing gates and valves. A little extra force applied to the control transmits extreme pressure through the threaded stem. It is a good practice to install stop nuts on the gate stem to limit the range of travel of the gate and to prevent overstressing of the gate in the closed position.

Surface Coatings

Water gates and valves are subjected to conditions which cause surface deterioration, such as wetting and drying, abrasion from water borne materials , and ice and freezing action. These conditions cause rapid damage to surface coatings. It is important that the surfaces be examined periodically, and repairs made as required to prevent rust and other damage. The coating materials should be compatible with the existing coatings and of a quality to provide maximum protection. The surfaces to be treated should be clean and dry and the material applied in accordance with the manufacturer's instructions.

Protection From Fire

Gate installations that collect weed growth or streamflow containing trash that may collect on the gate can cause maintenance and operation problems. Fire should not be used to remove these materials. Damage to surface coatings will result and it is possible under certain conditions to cause warping or other damage to the gate assembly. Also, intense heat may damage the surfaces of concrete structures. Often trash barriers may be constructed upstream from the gate that will make trash removal by burning practical.

Lubrication

All gate assemblies should be lubricated in accordance with the manufacturer's instructions. Lubrication of the threaded portion of the gate stem and the control assembly is especially important to prevent wear.

9. METALWORK

MATERIALS

Steel Shapes

Angles, channels, and wide flanges are the most commonly used standard steel shapes. These materials are manufactured in a wide range of dimensions. Structural steel meeting the requirements of ASTM A-7 (Steel for bridges and buildings) is available at most shops and is of adequate quality for normal installations. High strength steels may be specified for use to meet extreme conditions.

Steel Pipe

Seamless and welded black and zinc coated pipe meeting the requirements of ASTM A-120, ordinarily used for steam, water, gas and air lines is satisfactory for use in small structures. It is available from jobber's supply. The pipe is manufactured in standard, extra strong, and double extra strong weights. Standard thread or weld connections may be used for fabrication.

Bolts

Low carbon steel externally and internally threaded standard bolts that meet the requirements of ASTM A-307 usually are available from local hardware dealers and have adequate strength for most work. These fasteners are available in square or hexagonal heads, and may be supplied with zinc coatings when field conditions demand extra protection.

KINDS OF INSTALLATIONS

Trash and Debris Racks

Fabricated assemblies which may consist of steel shapes, gratings of steel or pipe, or a combination of these materials are necessary for the control of trash that may cause clogging of water control structures. Typical structures where trash guards may be required include outlets for storage reservoirs and inlets for siphons, pipelines, pumping stations, storm drains, irrigation diversion and control structures and farm drain tile systems.

Guard Rails

Guard rails installed for the safety and protection of maintenance personnel and the public should be made a part of all structures that have inherent hazards. Assemblies of pipe and standard pipe fittings are economical, attractive, and easy to install.

Specially designed structural shapes or heavy channel sections may be used for road guard rails.

Other Structure Components

Metal is an economical construction material, and has wide use as parts of structures made from other materials. Typical examples include: collapsible or removable stanchions for stop log dams; slide grooves for stop logs; frames for trash screens; weir plates for water measurements; piling; posts; and many other minor units.

WORKMANSHIP AND ASSEMBLY

Cutting and Fitting

All metal fabrication should be performed by competent workmen. Metal shapes should be uniform in cross section and free from bends or distortion. Cutting and fitting should conform to plan dimensions. Burned or sheared surfaces should be accurate and neatly finished. All surfaces to be joined by welding should be ground and shaped to make uniform contact.

Bolted Connections

Bolted connections are not commonly used in assembly because of the extra labor cost. All holes should be drilled at right angles to the surface of the metal to provide uniform bearing surface for the bolt head and nut. Bolts should have sufficient length to extend completely through the nut when in final position. All bolts should be tightened to make a rigid joint, but not overstressed.

Welding

All welds should be made by competent operators. The electric arc process is the most practical and is recommended for all types of assembly. The metal surfaces to be welded should be free from slag, paint, grease, oil, moisture or other foreign materials. The completed weld should have good penetration, and be free from pin holes, undercuts, and cracks. The weld should present a uniform cross section complying with the location and dimensions shown on the drawings. Assemblies warped or distorted due to uneven or improper welding heat should not be accepted.

Anchorage

Metal assemblies are often anchored to foundations or other parts of the structure. Anchorage by welding to metal embedded in concrete requires care to prevent heat transmission that would damage the concrete.

Some assemblies are installed on concrete by means of lugs or anchor bolts. These should be carefully positioned in the forms and the concrete consolidated around them so that complete contact is made. Metalwork attached by bolts often presents assembly problems in the field. It is desirable to have the metal unit on the job at the time anchor bolts are set so that proper spacing can be measured. An alternate is to burn the holes to match the in-place anchor bolts at the job site. Holes made with a welding torch should be well formed to proper size. All material that protrudes beyond the normal metal surface due to the burning operation should be removed. Anchor bolts should be washered and wrenched tight. Holes drilled in concrete or wood for expansion or lag screws should be accurately located and made to proper dimension. The screws should be tightened for maximum anchorage.

SURFACE PROTECTION

Paint

All metal surfaces not embedded in concrete should be given a protective coating to minimize the formation of rust and corrosion. Coatings of coal tar mixtures, vinyl, phenolic or red lead and aluminum paints are commonly used. The metal surfaces should be thoroughly cleaned to remove rust, scale, dirt, oil and grease. The surfaces should also be dry and have a temperature above 40 degrees F. at the time of treatment. Paint materials should be mixed and applied as recommended by the manufacturer. The coating should be applied at a rate that will result in a uniform surface free from runs, ridges, or drips. Two or three coats are normally required to produce an adequate protective film. Sufficient time should be allowed for drying, and the surface of each coat cleaned as necessary before applying the next coat.

Galvanizing

Metal surfaces should be thoroughly cleaned prior to adding zinc coatings. Insofar as practical, cutting, welding and complete assembly should be made prior to galvanizing, thus preventing damage to the coatings. The hot-dipped process is commonly used; however, satisfactory coating can be attained by the electro-galvanizing process. Visual examination should be made at the time of installation to see that all metal surfaces are covered and that the coating is free from blisters, flux, black spots or projections. The coating should form a tough bond with the metal, one that will not peel or crack when tested with a sharp knife. The metalwork should be installed in a manner that prevents abrasion or other rough contact that damages the coating.

10. TIMBER FABRICATION AND INSTALLATION

MATERIALS

Lumber

Inspection and Grading

Lumber is graded by visual examination of the piece to determine the location, size and nature of knots and other surface features which may affect the strength. Associations exist over the country that establish grading and dressing rules that apply to lumber manufactured from specific species of trees.

Marking and Stamping

To verify the quality of lumber delivered to the job, it is necessary to know the standard markings used by the Association or inspection bureau. "Construction," "standard" or "utility" are the more common grades used for structures. Grading rules and markings are available for inspection at most commercial lumber yards.

Hardware

Machine bolts and dowels should be medium steel or wrought iron with square heads and nuts.

Washers may consist of cast ogee gray iron or malleable castings, cut steel, or wrought iron flats.

Nails and spikes should be cut wire of commercial quality.

All hardware items should be galvanized as specified on the drawings.

Preservatives

The treatment of lumber and poles is recommended to increase the durability of the wood fiber under various conditions of exposure. Commonly-used preservatives consist of creosote-tar mixtures or various compounds of arsenate, zinc, chromium or pentachlorophenal. The preservative may be applied by brushing or dipping on the site. Field application should be in accordance with the manufacturer's instructions.

Lumber and piles may also be purchased that have been pressure treated by commercial plants. Commercial processing is usually performed by methods that conform to standards established by the "American Wood Preserver's Association" (AWPA). Pressure-treated materials should be stamped by the processor to indicate the name of the plant, kind of preservative and the pounds per cubic foot that was absorbed by the wood.

KINDS OF STRUCTURES

Irrigation

Flumes

Structures that convey water for continuous periods should be constructed from good quality, finished tongue-and-groove lumber. Materials of this type are kiln dried and require slight spacing of each piece to allow for the swell. The lumber used for substructures and framing should be the specified grades.

Lumber for flume construction requires expensive grades, and the project should be carefully planned and constructed.

Checks, Drops and Turnouts

Irrigation structures of this type are often shop assembled. The quality of the materials may vary depending on cost and availability of the required lumber. It is desirable to have lumber that is free of loose knots, splits and checks. The surfaces may be finished or unfinished. The structure should be relatively watertight, with strength to resist water and backfill pressures.

Chutes

The quality of material required for chute construction depends on capacity, frequency of use, and the hazard of the site. Where leakage can result in serious erosion or endanger the structure, good quality materials and construction are necessary. The design and precautions used in constructing flumes are applicable to chute construction.

Farm Bridges

Farm bridge construction requires lumber that is capable of supporting tractors and other heavy loads. Inspection of the materials furnished to the site is important since safety to human life is involved. The lumber should show the specified grade stamp and, when applicable, the preservative treatment applied.

Components of Other Structures

Lumber materials also are used to construct replaceable parts of structures that are made primarily from more permanent materials. Typical examples include stop logs, catwalks, and shelter houses for gate controls.

SIZES AND LENGTHS

Rough (Unfinished) Lumber

Lumber size is denoted by thickness, width and length, in that order. The sizes listed on the drawings are nominal dimensions. For unfinished lumber, not kiln dried, the material usually meets or exceeds the nominal thickness and width.

Dressed Lumber

Dressed lumber sizes are less than the nominal size. For example: after dressing, 1 x 4 flooring measures 25/32 inch x 3-1/2 inches; a finished 2 x 4 measures 1-5/8 x 3-5/8. For lumber over 2 inches thick, the thickness and width are 3/8 inch scant for faces under 8 inches and 1/2 inch for faces over 8 inches. Lumber materials are available in multiples of 2-foot lengths from 4 to 20 feet. Structure grades can be furnished in longer lengths on order.

STORING AND HANDLING

Piling on the Site

Lumber should be piled off the ground on supports so placed that proper shape of the material is maintained. In stacking, one end should be raised to provide drainage. Kiln-dried and finish lumber should be stored under cover.

Surface Damage

Methods used in transporting and handling should prevent damage to the surface faces or edges. This is especially important for treated lumber or poles. Sharp-pointed tools or hooks should not be used to handle treated timber. Rope or other nonmetallic materials are commonly used for handling on the job.

INSTALLATION

Cutting and Framing

All carpentry should be done by competent workmen. Measurements should be accurate and cuts made true to line and shape. Joints should have even bearing without the use of shims. Insofar as practical, cutting, framing and boring should be accomplished prior to adding preservative treatment.

Nailing

Nails and spikes should be driven straight and true to position and only until the head is just flush. Deep hammer marks cause damage to the wood fiber.

Bolting

Holes for bolts should be bored 1/16 inch oversize, and at right angles to the face of the material. Bolts should be provided with washers of the correct size at both ends. The bolts should not be tightened to cause deformation of the wood fibers.

Treating Damaged Surfaces

Field cuts or drilled holes made in treated lumber should be coated with the same preservative as used in the original process. Likewise, damaged surfaces or corners of all treated lumber should be treated in the field. Factory or shop paint coatings that are damaged prior to or during installation need to be touched up to restore appearance and to provide satisfactory protection.

11. MASONRY

MATERIALS

Stone

Stone (rock) suitable for structures should be:

1. Hard and durable.
2. Available in blocks of sufficient size to form the elements of the structure.
3. Of suitable texture for shaping as required.

Limestone and sandstone are commonly used in small structures since these materials are widely distributed and are more easily quarried and shaped for construction purposes. Since rock can vary in quality, advice should be requested from a geologist if the acceptability of a specific source of rock is doubtful.

Concrete Blocks

Preformed concrete blocks may be purchased from commerical manufacturers. The process of manufacture includes the use of a dry concrete mix which is placed in a metal mold and compacted by mechanical pressure or tamping equipment. Proper mix and operating procedure permits immediate form removal for reuse. Due to the relatively dry mix and method of manufacture, the product tends to be porous and may not prove to be as durable as stone masonry under severe operating conditions. The blocks are commonly manufactured in 8 x 8 x 16 inches (regular building block) and 8 x 8 x 8 inches, half size. Other dimensions may be available at certain locations.

Mortar

Masonry, whether constructed of stone or concrete blocks, requires a mixture of sand and cement to join the separate components into an impervious stable mass.

Cement

Should be portland cement of the specified type, which may vary depending on the soil and water conditions that prevail. Type I or Type II are usually satisfactory.

Sand

The fine aggregate should consist of clean, durable particles which meet the requirements for aggregate used in concrete manufacture. Sand that passes the number 16 sieve gives better workability and is preferred.

Water

Mixing water should be free from injurious amounts of oil, acids, salts or organic matter. Water from domestic supply should be used when available.

KIND OF STRUCTURES

Masonry is suitable for construction of small erosion and water control structures. The use of concrete blocks has economic advantage due to the extra labor usually required in obtaining and shaping stone material. Masonry has low resistance to tensile forces. Vertical stone walls require designs that provide the necessary stability by utilizing the weight of the material to resist earth and water pressures.

Walls constructed with concrete blocks that have hollow cores may be reinforced by matching and filling the openings with good concrete. Added stability may be provided by inserting vertical reinforcing bars into the blocks before filling the openings with concrete.

Drop Structures

Structures of good quality stone give economical service under moderately severe operating conditions, which include heavy flows and freeze and thaw temperatures.

The stability and bearing capacity of the foundation is very important for masonry structures. They have high unit weight and the wall sections often require considerable thickness to provide stability. Cracking due to differential settlement can result in failure of the structure.

Concrete blocks are not commonly used for high drops or for operating conditions that include continuous flows and severe weather conditions.

Chutes

Stone masonry has some application for small chutes, provided high velocity flow is not involved. Usually chutes are installed in locations which involve short, steep profiles where the erosion can be controlled more economically with pipe or concrete lining.

Concrete blocks are not recommended for chute construction.

Checks and Turnouts

These small field structures may be constructed from masonry and will perform satisfactorily, provided good quality materials and workmanship are obtained. Stone materials are not commonly used due to the labor required to provide and shape the rock.

Concrete block masonry has considerable application because of the uniformity of shape and the availability of material supply. Anchor bolts for stop log angles or formed notches may be readily adapted to the job requirements. Structure designs based on concrete blocks usually include a concrete floor slab and cutoff walls to assure stability and good performance.

INSTALLATION

Satisfactory life and performance of any structure depends on good construction procedures throughout all phases of the work. The following operations require close adherence to requirements outlined in the plans and specifications.

Foundation Preparation

After the excavation is completed to the lines and grades, the subgrade should be inspected to see that the foundation material is well compacted and has adequate bearing capacity to support the structure. Uniformity of the exposed materials and the absence of any conditions that would result in uneven settlement is necessary to prevent cracking and displacement in the masonry. Wet sites, unless drained and stabilized, should not be used.

Batching and Mixing Mortar

Mortar should be carefully batched by volume or by weight to provide the proportions of cement and sand specified for the work. A mix of 1 part cement to 2 parts sand is commonly used for the initial layers. Pointing mortar, when required, is often mixed 1 part cement to 1 part sand. The amount of mixing water should be limited to the minimum amount that will produce a workable mix, but preferably on the dry side to reduce shrinkage and cracking. The mortar should be uniformly mixed and used within 45 minutes. Machine mixed mortar tends to be more uniform and is preferred over hand mixing.

Placing Stone or Blocks

The size and finish of the individual stones and the methods of laying should be shown on the drawings. For conservation structures, the requirements for shaping or cutting to provide joints having less than 1/2 inch between surfaces of adjoining stones (Ashlar Masonry) can rarely be justified. Rubble masonry, which consists of unsquared stone, is more economical and is adequate for small structures.

The method of placing the stone in each course may be specified as Range Masonry, in which a course is the same thickness throughout; Broken Range, in which the course is uniform in thickness for only parts of its length; or Random Masonry, which means that the stone is not laid in courses.

Stone for rubble masonry, when placed, should be clean and dust free. Sharp acute angles should be removed from the block. The stone should be kept moist for an hour prior to bedding in the mortar. Other requirements to be considered are:

1. The largest stones should be used in the foundation or lower portion of the walls.

2. Each stone should be laid on its broadest face.

3. Stratified stones should be laid with the strata perpendicular to maximum pressure, usually horizontal.

4. No joint in any course should be directly above a joint in the course below.

5. Do not move a stone by sliding after it has been bedded in the mortar. To prevent moving other in-place stone, lift the stone to be moved and reset it in proper position.

Concrete blocks usually are placed in a uniformly coursed pattern (range masonry) with evenly distributed overlapping or bonding of each course. Half-length blocks are used as required to provide the proper spacing for each course. The blocks should be well moistened just prior to placing in the bedding mortar.

Placing Mortar

Adequate mortar should be used to completely surround the jointing surfaces of the stone. Due to the irregular surfaces the thickness of the mortar will vary from a minimum of approximately 3/8 inch to the requirements to completely fill all voids. Adequate bedding mortar should be evenly spread so that the stone can be lightly tapped to insure complete contact. Often rock spalls can be embedded in the mortar to reduce the space and save mortar.

When so specified, the exterior edges of the joints should have the mortar recessed about 1 inch to receive pointing mortar. The recessed areas should be moistened just prior to applying the pointing mortar. Proper sealing of the joints is important to prevent the entrance of moisture which may cause freeze-thaw deterioration.

The jointing surfaces of concrete blocks should be completely surrounded by approximately 1/2 inch of mortar. The bedding layer should be uniformly spread and the jointing ends of the blocks coated prior to placement. As the block is placed, it should be lightly tapped to line and grade and the exposed joint surface finished flush and smooth. A chalk line set to line and grade is recommended when laying long walls.

Curing and Protection

Mortar used in masonry has a high cement content and is subject to quick set and high shrinkage. In hot weather the masonry should be kept moist for 2 or 3 days. Wet coverings, fog nozzles, or spraying may be used. Masonry construction should not be performed if freezing temperatures are anticipated, unless adequate cover or housing is available to protect the structure. The mortar should be protected from freezing for a minimum of 5 days.

12. ROCK RIPRAP

MATERIALS

Quality of Stone

Riprap consists of stone of various sizes, placed compactly or irregularly, to prevent the scouring action of water.

Stone used for riprap should be dense and hard enough to withstand exposure to air, water and freezing temperature. The suitability of a specific source of stone may often be evaluated by study of the performance of the rock used on other projects. For stone of unknown quality, it is desirable to have an appraisal made by a geologist. Some stone appears satisfactory at the time of harvesting but may disintegrate within a few years. Rough angular stone reasonably well graded in size, as commonly produced in quarries, is the preferred type of material. Smooth rounded surface stone does not interlock or resist movement as well as quarry stone.

Stone for hand-placed construction may be specified for special appearance and to utilize thin-bedded material (6 to 12 inches) which may be shaped and placed on edge.

Bedding

Sites to be riprapped, which include steep earth banks of stream channels or dams, often require additional protection to prevent the erosion of fines from under the stone blanket. This erosive action by water may cause uneven settlement of the stone and failure of the riprapped section. For these conditions a layer of sand, gravel, rock spalls, or a combination of these materials is placed on the earth slope to the specified thickness. Usually 4 to 8 inches is sufficient. These granular materials form a bedding layer that prevents erosion of the underlying soil and supplements the riprap protection. All materials used for bedding should be hard, durable, and capable of functioning for the life of the rock riprap.

Grouted rock riprap installed at sites having questionable drainage characteristics may require a layer of drain material placed beneath the riprap. This material should meet all the requirements previously specified for other types of stone structures.

Grout

Grouted riprap consists of loose rock completely bonded into a solid mass by filling the voids with a mixture of concrete. The grout is a regular concrete mixture with a limitation on the maximum size of coarse aggregate, usually 3/4 inch. All ingredients should be of a quality normally used for other concrete construction. The mix should be proportioned to contain a minimum of 5 bags of cement per cubic yard and produce a slump within a range of 6 to 11 inches. The grout should be machine mixed. Often transit mixers can deposit the grout directly upon the in-place rock sections.

ADAPTABILITY

Loose Rock Riprap

Machine or hand-placed riprap has proven to be a satisfactory construction material for protecting all classifications of soils from erosion caused by water under medium to low velocity flow.

Structures that may be protected with loose rock include stream channel banks, constructed slopes for dams and dikes, inlet and outlet sections adjacent to various kinds of water control structures, bridge abutments, and culvert inlets and outlets. The determination to use rock riprap for a specific project should be based on the site conditions and the comparable costs of installing other permanent types of protection.

Grouted Rock Riprap

Grouted rock is suitable for protecting the same site situations that are adapted for loose rock riprap. Grouted rock provides added stability to resist high velocity flow and ice action. The use of grout also makes it possible to utilize small stone that would not be adequate if placed as loose riprap.

INSTALLATION

Foundation Requirements

The foundation requirements for rock riprap are similar to those for concrete and other types of permanent structures. The surfaces on which rock or bedding materials are placed should be well compacted and stable. The foundation excavation for the toe sections for streambank protection should be down to an elevation that is safe from scour or degradation of the channel bottom. Displacement of the toe rock removes support for adjacent stone, and the chain reaction may result in complete failure of the riprap section. It is also important to make sure that the beginning and ends of the treated section are adequately entrenched into the banks to prevent undermining.

The stability and drainage of the foundation for grouted rock riprap is essential, since the sections are commonly placed continuously without joints or provisions for uneven settlement. Foundations that present drainage problems should be treated with filter material and weep holes as specified.

Shaping Earthwork

The surface on which bedding materials or rock riprap is to be placed should be graded to the lines and grades shown on the drawings. The subgrade should be checked for loose material or soft areas prior to placing the protective materials. Excavations made adjacent to structures require caution to prevent damage to the structures.

Placing Rock

The riprap should be placed in the manner specified. Hand-placed riprap requires an excessive amount of labor and for this reason is not commonly used on small structures. Machine-placed riprap requires hand labor only as necessary to prevent damage to structures and to produce the thickness or surface finish required. This is the common installation procedure. Placing equipment may include front-end loaders, clam buckets, dragline buckets or crane-operated skips. The riprap should be placed to the full course thickness in one continuous operation, and by methods that prevent displacement of the bedding or filter materials. The placement of loose riprap should result in a reasonably well graded mass, with sufficient small stone to fill the voids between the large rock.

Placing by dumping from trucks or by spreading with dozers tends to segregate the rock sizes and should not be used for placing unless additional precaution is taken to maintain uniformity of the gradation.

Rock placed for grouted sections should be graded to remove the major portion of the material less than 4 inches in size. The rock should be arranged to eliminate large pockets. Stone should not be decked one above the other to meet thickness requirements. Hand labor should be utilized as required to improve the arrangement and to produce the thickness and surface specified for the work. Prior to placing grout, the rock should be washed using water pressure as required to expose a clean surface.

Placing Grout and Protection

The rock riprap should be kept wet immediately ahead of the placing of the grout. The grout may be placed with crane buckets, chutes, pipes, or other conveyance. The grout should land on a splash plate of wood or steel to prevent movement of the rock. A strip about 10 feet wide should be covered at a time. On slopes, the grouting operations should start at the bottom and proceed upslope. Shovels and stiff bristle push brooms are used to direct the grout and to prevent excessive movement. It may be necessary to place the grout in two courses on steep slopes to control the movement of the grout within the rock voids. The time allowed between the placing of the two courses should permit only partial set of the grout.

It is important that the two courses form a good bond. During the progress of the work, inspection should be made to determine that the grout penetrates the full thickness of the riprap and that the voids are completely filled. The final cleanup and finish should remove excess mortar from the rock surfaces and result in sufficient mortar to fill the voids and be free from runs or ridges.

The freshly-placed grout should be protected from rain, flowing water, and injury caused by movement of workmen or equipment for a period of not less than 24 hours. During hot weather the grouted surface should be protected by wetted surface covering or by spraying with curing compound.

Grout should not be placed if temperatures are expected to reach 32° F. within 5 days after placement, unless adequate protective cover is provided to prevent freezing.

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